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The Rise of Ticks and Tickborne Diseases in the United States—Introduction

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Ticks and tickborne diseases have been recognized as threats to the health of humans and domestic animals for more than a century in the United States. However, as outlined in the following series of papers, the nature of this threat has evolved over time in response to changes in the natural environment, tick and wild animal populations, and human land use. Another major factor in this still unfolding story is our continuously improving capacity to detect and characterize tickborne disease agents.

Some of the most notable developments in the history of ticks and tickborne diseases in the United States include the following:

- The seminal work published by Smith and Kilborne in 1893, documenting for the first time experimental transmission of a disease agent—the parasite now called *Babesia bigemina*, which causes Texas cattle fever—via the bite of a blood-feeding arthropod, the cattle tick now called *Rhipicephalus annulatus* (Say);
- The demonstrations in 1906 and 1924 of experimental transmission by the Rocky Mountain wood tick, *Dermacentor andersoni* Stiles, of the agents causing Rocky Mountain spotted fever and tularemia in humans (Ricketts 1906, 1909; Parker et al. 1924; Parker and Spencer 1926);
- The incrimination in the late 1970s and early 1980s of the blacklegged tick, *Ixodes scapularis* Say (including the junior synonym *Ixodes dammini*), as the vector of both a parasite causing human babesiosis (Spielman 1976) and a spirochetal bacterium causing Lyme disease (Steere and Malawista 1979, Burgdorfer et al. 1982);
- The recognition in the 1990s that the human-biting lone star tick, *Amblyomma americanum* (L.), is an important vector of bacterial agents causing human ehrlichiosis (Walker and Dumler 1996, Childs and Paddock 2003).

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As a result of these and other developments, the focus of research on ticks and tickborne diseases in the United States has shifted dramatically over the last century. Up to the early 1970s, research focused primarily on human-biting *Dermacentor* ticks—the Rocky Mountain wood tick, *D. andersoni*; the Pacific Coast tick, *Dermacentor occidentalis* Marx; and the American dog tick, *Dermacentor variabilis* (Say)—and their associated pathogens, including spotted fever group rickettsiae, the tularemia agent *Francisella tularensis*, and Colorado tick fever virus (Sonenshine et al. 1972, Hopla 1974, Jellison 1974, Burgdorfer 1977). Bites by *D. andersoni* and *D. variabilis* also were associated with tick paralysis caused by a toxin in the tick saliva (Gregson 1973, Gothe et al. 1979). The emergence of Lyme disease in the 1980s led to a very strong focus on this human illness and the two species of *Ixodes* ticks that serve as the main vectors of *Borrelia burgdorferi* sensu stricto to humans in North America: the blacklegged tick, *I. scapularis*; and the western blacklegged tick, *Ixodes pacificus* Cooley & Kohls (Burgdorfer 1984, Spielman et al. 1985, Lane et al. 1991, Spielman 1994, Piesman and Gern 2004). Several factors contribute to a continued strong focus on *I. scapularis*, including the still ongoing geographical expansion in the range of this tick in the eastern half of the United States to place new human populations at risk, a steady rise over the last 30 yr in reported Lyme disease cases, more recently documented increases in two other *I. scapularis*-associated diseases, anaplasmosis and babesiosis, and transmission by this tick of an encephalitis virus (Powassan virus, including the deer tick virus subtype) which is a growing concern (Ebel 2010, Eisen et al. 2016, Schwartz et al. 2017, Eisen and Eisen 2018, Rosenberg et al. 2018, Sonenshine 2018).

Parallel with research on *Ixodes* ticks and their associated disease agents, there has been an increased focus on *Amblyomma* ticks since the 1990s due in large part to the recognition of the role of *A. americanum* as a vector of *Ehrlichia chaffeensis* and, more recently, of the Gulf Coast tick, *Amblyomma maculatum* Koch, as a vector of a human-pathogenic spotted fever group rickettiae (*Rickettsia parkeri*) (Childs and Paddock 2003, Paddock and Yabsley 2007; Goddard and Varela-Stokes 2009; Paddock and Goddard 2015, Eisen et al. 2017). Both of these *Amblyomma* species are expanding their ranges northward (Springer et al. 2014, Paddock and Goddard 2015, Sonenshine 2018, Molaei et al. 2019) from their historical distribution in the southeastern United States, and there is mounting evidence to suggest that bites by *A. americanum* may be associated with an allergic reaction (Alpha-gal syndrome) to consumption of red meat (Commins et al. 2011, Crispell et al. 2019, Mitchell et al. 2020). The most recent notable developments in the history of ticks and tickborne diseases in the United States include (1) the recognition of the brown dog tick, *Rhipicephalus sanguineus* sensu lato, as a vector of the Rocky Mountain spotted fever agent (*Rickettsia rickettsii*) (Demma et al. 2005, Drexler et al. 2014); (2) the discovery of new human-pathogenic viral agents (Bourbon virus and Heartland virus) associated with *A. americanum* (McMullan et al. 2012; Lambert et al. 2015; Godsey et al. 2016, 2021; Savage et al. 2017; Brault et al. 2018); and (3) the establishment and spread of the invasive Asian longhorned tick, *Haemaphysalis longicornis* Neumann, along the Eastern Seaboard (Beard et al. 2018, Rainey et al. 2018).

Bearing in mind the successive addition of species of ticks and tickborne pathogens described above to the overall negative impacts that ticks have on human health and well-being, it is not surprising that tickborne infections now account for more than 75%

of all reported vector-borne disease cases in the United States (Rosenberg et al. 2018). In 2017, a record number of cases (*n* = 59,349) of all notifiable tickborne diseases was reported to the Centers for Disease Control and Prevention (CDC) (Beard et al. 2019). With 42,743 cases reported in 2017, Lyme disease was the sixth most common of all notifiable infectious diseases and conditions in the United States. Moreover, it has been estimated that >450,000 Lyme disease cases occur annually in the United States (Kugeler et al. 2021).

As described in more detail in the following series of papers, progress is slowly being made to increase awareness of the public health significance of ticks and tickborne diseases. Although there is substantial work to be done to reverse the trend of increasing tick-related health threats, significant advances have been made in recent decades. Recent efforts to survey existing national tick surveillance capacity and invest in improved tick and tickborne pathogen surveillance have allowed us to better monitor changes in the distribution and abundance of ticks and the presence and prevalence of tickborne pathogens (Eisen and Paddock 2021, Mader et al. 2020). Diagnostic technologies have improved to identify tickborne organisms of medical and veterinary importance and to differentiate them from nonpathogenic organisms found in ticks (Tokarz and Lipkin 2021). Understanding how ticks and tickborne pathogens have evolved and adapted to changing host, environmental and climatic conditions, or how landscape modification or host composition impacts human encounters with infected ticks provides foundational knowledge on risk factors that can be used to disrupt transmission cycles and ultimately prevent human illness (Barbour and Gupta 2021, Diuk-Wasser et al. 2021, Ogden et al. 2020, Tsao et al. 2021). A wide range of tick and pathogen suppression methods have been developed and evaluated in small-scale studies, and efforts are underway to determine which of these are affordable, acceptable, and effective enough in reducing human tick bites and preventing human illness to ultimately be implemented at broad scales to reverse the trend of increasing incidence of tickborne diseases (Eisen and Stafford 2021). However, without immediate and sustained advances in these fields, the alarming trend of increasing tickborne diseases is likely to continue.

The articles in this special Forum issue have been written by some of the leaders in the field of ticks and tickborne diseases, and highlight key accomplishments, significant information gaps, insights into trends and drivers, and identification of high priority needs. There have been, in fact, a number of thoughtful and comprehensive review articles written in recent years on many of these areas of concern. The primary purpose of this series of papers is to provide an update on the situation, a platform to reach back to earlier contributions, and a renewed call to action. The 1989 classic movie *Field of Dreams* is famous for the quote "*If you build it, he will come*." The purpose of this series of articles is to build a compelling and urgent case for addressing the growing problem of ticks and tickborne diseases, which is by some accounts the most significant vector-borne disease challenge we have ever faced in the United States (Rochlin et al. 2019), in hopes of attracting the interest and investment necessary to turn the tide.

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