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Truncated seasonal activity patterns of the western blacklegged tick (*Ixodes pacificus*) in central and southern California

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ABSTRACT

Patterns of seasonal activity and density of host-seeking western blacklegged ticks, *Ixodes pacificus*, were investigated in central and southern California. Weekly to monthly drag sampling was undertaken at two sites in Santa Barbara County and one site in Los Angeles County over multiple years. Adult *I. pacificus* became active in the winter (late November) and were rare or absent by late April to early May. Nymphal ticks became active in early to late February, were absent by early May to early June, and were rarely encountered using the drag method throughout their period of peak seasonal activity. Larval ticks became active earlier in the season, or at the same time as nymphs (early to late February) and were absent by early May. These results suggest a highly truncated period of *I. pacificus* seasonal questing activity, particularly apparent in the juvenile tick stages, in central and southern California relative to observed patterns in Lyme-endemic northwestern California. Notably, the highly truncated period of questing activity of the juvenile stages has important implications for pathogen transmission dynamics in that there exists only a brief window for horizontally transmitted pathogens to be acquired by one tick cohort and subsequently transmitted, through hosts, to the next tick cohort in this system. The broader patterns observed also suggest low human risk of tick-borne disease in central and southern California, and have implications for reduced tick-borne disease risk in the western US more generally under projected climate change.

Introduction

Globally, there has been an increase in the rate of emergence of vector-borne zoonotic diseases in recent decades, presenting new challenges and threats to public health (Jones et al., 2008; Kilpatrick and Randolph, 2012). A number of large-scale anthropogenic changes, such as land use and climate change, are contributing to the amplification of emerging infectious zoonotic diseases. For example, the distribution of vector species may shift or expand as a result of climate change, and lead to subsequent shifts in vector-borne disease burden (Bounoua et al., 2013; Ogden et al., 2008b). In the case of pathogens with complex transmission cycles involving multiple hosts and vector life stages, changing host ecology resulting from land use or environmental change may also alter human disease risk through vector abundance (Ogden et al., 2014), infection prevalence with the pathogen (Allan et al., 2003; Patz et al., 2004), or vector activity patterns (Ogden et al., 2008a). Thus, understanding when and where vector species are active and how these patterns may be expected to change given ongoing climate or environmental change is crucial to prevention and control of vector-borne diseases.

Lyme disease is the most commonly reported vector-borne disease in the United States, and is increasing in incidence and geographic range (Bacon et al., 2008). In the United States, Lyme disease is caused by an infection with *Borrelia burgdorferi*, a spirochete that is transmitted to humans by blacklegged ticks—*Ixodes scapularis* in the eastern United States and *Ixodes pacificus* in the western United States. In addition to *B. burgdorferi*, both blacklegged and western blacklegged ticks vector a number of other emerging pathogens including the causative agents of tick-borne relapsing fever (*Borrelia miyamotoi*), anaplasmosis (*Anaplasma phagocytophilum*), and babesiosis (*Babesia* spp.). *Ixodes* spp. ticks have a four-stage life cycle, comprised of the egg stage and the parasitic larval, nymphal and adult stages, and maintain enzootic transmission of *B. burgdorferi* in complex cycles involving many different vertebrate hosts (Gray et al., 2002; Kurtenbach et al., 2006). *B. burgdorferi* is not transmitted transovarially and can be acquired by larval and nymphal ticks only through blood meals taken from infected hosts, and thus infections may be transmitted only by infected nymphal or adult female ticks (Clover and Lane, 1995; Falco et al., 1999; Gray et al., 2002; Kurtenbach et al., 2006). Seasonal activity and density of potentially

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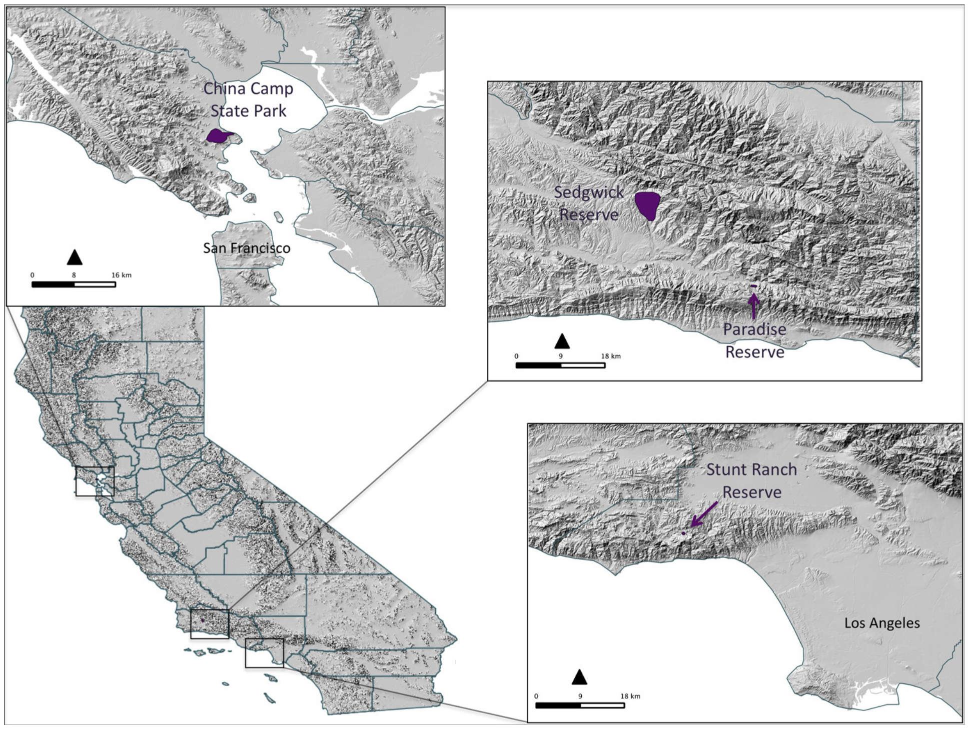

Fig. 1. Map of tick sampling sites in northwestern, and southern California. California hillshade data layer was obtained from Cal-Atlas (www.atlas.ca.gov/download.html) through https://koordinates.com.

infectious tick life stages are thus critical components of Lyme disease risk.

In the eastern US where human Lyme disease is most common, larval *I. scapularis* peak in activity in the early fall (August–October) in the northeastern US, and in the summer months (June–August) in the upper Midwestern US, while nymphal *I. scapularis* peak in activity during the summer months (June–August) and adult *I. scapularis* have bimodal peaks in activity during the fall and spring (Falco et al., 1999; Gatewood et al., 2009; Hamer et al., 2012; Ostfeld et al., 1996). Consequently, because nymphal *Ixodes* spp. are the primary vector, peak Lyme disease transmission in the eastern US occurs during the summer months when nymphal ticks are most active (Falco et al., 1999), and Lyme disease risk is absent during the winter months when much of the northeast and upper Midwest is blanketed in snow or experiencing temperatures consistently below 0 °C. In contrast, in western North America, the area of highest risk for acquiring Lyme disease is northwestern California, where vector ticks have been found to be active throughout the year, presenting a year-round risk of Lyme disease transmission (Salkeld et al., 2014).

In central and southern California, infected *I. pacificus* ticks have been identified, but transmission of *B. burgdorferi* to humans is less common (Padgett et al., 2014). A handful of previous studies suggest that infection prevalence in vector tick populations in central and southern California – with both *B. burgdorferi* as well as the relapsing fever spirochete, *B. miyamotoi* – is low (Lane et al., 2013; Padgett et al., 2014), which is likely contributing significantly to the low rate of transmission to humans in this region. However, the underlying mechanism producing low infection prevalence in southern California tick populations is not well understood. Here we examine one possible mechanism, namely the seasonal activity patterns of the western blacklegged tick, and investigate whether this vector species exhibits a truncated period of seasonal activity in southern California. We report on seasonal activity patterns of *I. pacificus* in sites in Santa Barbara County and Los Angeles County, California in which weekly to monthly tick collection was undertaken over multiple years. We show that *I. pacificus* activity patterns, particularly of the juvenile stages, are truncated relative to those observed in northwestern California. We discuss possible causes of these observed patterns, implications for human tick-borne disease risk in central and southern California, as well as implications for tick-borne disease risk under projected climate change in the western US.

Materials and methods

I. pacificus ticks were collected at three sites in Santa Barbara and Los Angeles County, California to determine seasonal activity patterns and timing of peak density in central and southern California. Santa Barbara County collection locations included Sedgwick Reserve, part of the University of California Natural Reserve System and located in the Santa Ynez Valley, and Paradise Reserve located in the Los Padres National Forest on the north side of the Santa Ynez Mountains (Fig. 1). Collection sites in Sedgwick Reserve were characterized by oak woodland, consisting of coast live oak (*Quercus agrifolia*), blue oak (*Quercus douglasii*) and occasional valley oak (*Quercus lobata*). The understory was dominated by introduced grasses including brome (*Bromus* spp.), wild oats (*Avena* spp.) and occasional native bunch grasses, as well as common vetch (*Vicia sativa*) and California sagebrush (*Artemisia californica*). Collection sites in Paradise Reserve were characterized by similar plant communities, notably coast live oak woodland with occasional California bay-laurel (*Umbellaria californica*) and an understory dominated by introduced grasses and western poison-oak (*Toxicodendron diversilobum*). In Los Angeles County, ticks were collected from Stunt Ranch Reserve, also a part of the University of California Natural Reserve System, in the Santa Monica Mountains (Fig. 1). Collection sites in Stunt Ranch Reserve were also characterized by coast live oak woodland with an understory dominated by introduced grasses and western poison-oak.