Ticks and Tick-borne Diseases 10 (2019) 1113–1117

Contents lists available at ScienceDirect

Ticks and Tick-borne Diseases

journal homepage: www.elsevier.com/locate/ttbdis

Time of year and outdoor recreation affect human exposure to ticks in California, United States

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ARTICLE INFO

Keywords:
Citizen science
Vector surveillance
Tick phenology
California Lyme disease
Tick seasonality

ABSTRACT

Interactions between humans and ticks are often measured indirectly, using surveillance of tick population abundance and pathogen prevalence, or reported human disease data. We used data garnered as part of a free national citizen science research effort to describe actual human exposures to ticks in California. Human-biting ticks (n = 1,905) submitted for identification were predominantly western black-legged ticks (*Ixodes pacificus*) (68%), American dog ticks (*Dermacentor variabilis*) (24%), and Pacific Coast ticks (*Dermacentor occidentalis*) (7%). Tick exposure occurred predominantly during recreational use of the outdoors, rather than exposure near the home environment. Tick submissions peaked in May, but human exposure to ticks occurred throughout the year. Adult *I. pacificus* were most frequently found on humans during March-May, though previous research demonstrates that questing adults on vegetation are more abundant earlier in the winter.

1. Introduction

Tick-borne zoonotic pathogens circulate in wildlife and tick populations, but there can be spillover into human populations when a person encounters an infected tick, is bitten by the tick, and the pathogen is successfully transmitted. Understanding the dynamics of these processes often involves surveillance of tick and wildlife populations to gain insight into vector abundance and pathogen prevalence; and reported human case data can inform epidemiologic investigations. However, it is not always easy to draw causative links between entomological indices and human disease cases (Connally et al., 2006; Eisen and Eisen, 2016; Nieto et al., 2018).

The phenomenon of human exposure to ticks receives relatively little attention (Eisen and Eisen, 2016; Nieto et al., 2018), perhaps because of the associated challenges. Achieving adequate sample sizes of people being bitten is not an easy undertaking, and there are the difficulties of identifying exactly where (geographically) and when the exposure to the tick occurred, as hard-bodied ticks may attach, bite and feed on a person for 2–3 days before being detected (Sood et al., 1997; Lane et al., 2004; Hamer et al., 2013). A good proportion of tick-bites, especially those of immature ticks, may go entirely unnoticed.

One approach to resolve these challenges is to use ‘citizen science’ – when members of the public collaborate with scientists to collect data and samples – which can be an effective strategy to amass data on human exposures to arthropod vectors of zoonotic pathogens (Mulder et al., 2013; Xu et al., 2016, 2019; Hamer et al., 2018; Nieto et al., 2018).

Here, we analyze data generated by a citizen science project on human-biting ticks (Nieto et al., 2018), to examine seasonal patterns and human activities associated with tick-exposures in California. In California, the western black-legged tick, *Ixodes pacificus*, is a proven vector of human pathogens including *Borrelia burgdorferi* sensu stricto, which causes Lyme disease (Lane et al., 1994; Eisen et al., 2006), and *Anaplasma phagocytophilum* which causes human granulocytic anaplasmosis (Foley et al., 2004; Nieto and Salkeld, 2016), and is the putative vector of *Borrelia miyamotoi,* which causes a relapsing fever (Salkeld et al., 2014a; Padgett et al., 2014; Krause et al., 2018), and *Borrelia bissettiae* (Girard et al., 2011). Xu et al. (2019) also recently described patterns of human-biting *Ixodes* spp. ticks in California. Two other important human-biting ticks in California are *Dermacentor variabilis*, the American dog tick, and *Dermacentor occidentalis,* the Pacific Coast tick. *Rickettsia philipii,* which causes Pacific Coast tick fever, is transmitted by *D. occidentalis* (Shapiro et al., 2010; Johnston et al., 2013; Padgett et al., 2016), and *Rickettsia rickettsii* has also been observed in *Dermacentor* spp. in California, albeit extremely rarely (Padgett et al., 2016).

Little research has described human risk factors for tick-bites in California (as opposed to factors influencing tick abundance in natural

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https://doi.org/10.1016/j.ttbdis.2019.06.004
Received 13 March 2019; Received in revised form 5 June 2019; Accepted 6 June 2019
Available online 07 June 2019

habitats, or pathogen serology which demonstrates previous exposure to pathogens but does not evaluate the actual tick-bites), and are often of limited geographical and human scale. Lane et al. (2004), working in black-oak woodland of Mendocino County, and using two human subjects, compared different human behaviors in woodland habitat for potential exposure to western black-legged ticks, determining that the riskiest behaviors for acquiring nymphal *I. pacificus* were (in descending order) sitting on logs, gathering wood, sitting against trees, walking, stirring and sitting on leaf litter, and just sitting on leaf litter.

We describe patterns of tick submissions by citizen scientists in California to examine the importance of human activity (e.g., recreational activity in natural areas) and time-of-year for tick exposure to three tick species.

2. Methods

Ticks were collected as part of a citizen science research project conducted from January 2016 to August 2017 that allowed members of the public to submit ticks for species identification and pathogen screening (Nieto et al., 2018). The project was advertised through an initial public relations campaign and then made available to the public via a web site (Bay Area Lyme Foundation, http://www.bayarealyme.org/lyme-disease-prevention/ticktesting/), which was further highlighted by Lyme disease interest groups.

Ticks were mailed in plastic zip-lock bags to Northern Arizona University, where they were identified to species, sex, and life stage, according to morphological characteristics based on standard taxonomic keys (see Nieto et al., 2018). Some ticks were unidentifiable (n = 32).

Each submission included a questionnaire requesting information on the perceived date and location (city, county, state) of the tick encounter, whether or not the tick was crawling or biting (i.e., had become attached to the person), host type, and activity the citizen scientist was participating in when the tick encounter most likely occurred. Data on tick submissions were assigned to the county where the tick was most likely collected by the person submitting the ticks. Submissions did not include information of recent travel history, and we accepted location information from the data submitted by the citizen scientist without verification. Responses to the activity were categorized based on the free form response of the citizen scientist. We excluded data when the answers were missing or unclear. Tick exposure data were placed into three broad categories. 1. outdoor recreation in natural areas – including hiking, dog-walking, horse-related activities, hunting, camping, fishing, biking, running, and climbing; 2. peridomestic exposures – any activities that occurred in close proximity to the home or yards and gardens, as well as dog-walking on personal lawns or within neighborhoods; and 3. exposures in other man-made environments such as golf courses, farming, and roadside activities. Farm-related activities included any activity which took place in/around man-made farming structures (i.e. barns) or on farmland (i.e. farm maintenance). Roadside activities included activities that occur in the presence of a road, i.e., road clean-up, getting into or pushing a car, walking on the highway shoulder, bathroom breaks along the road, and driving (though in the cases of 'driving' we assume that this is when the exposure was noted rather than where exposure occurred). It should also be noted that the difference between dog-walking in outdoor natural areas versus peridomestic exposures is the location where the dog-walking took place. Outdoor recreation dog-walking occurred in natural areas whereas peridomestic dog-walking occurred in areas near housing developments or neighborhoods.

No personal-identifying information was collected from citizen scientists for analyses (i.e., no name, age, gender, address), and because analyses focused on patterns of tick exposure, Northern Arizona University Institutional Research Board (IRB) determined that this was not human research and therefore did not require IRB approval.

3. Results

3.1. Tick species submitted

Between January 2016 and August 2017, we identified a total of 1,905 ticks that were recovered biting or crawling on people in California. The ticks most frequently found on people were the western black-legged tick (*I. pacificus*) (n = 1291, 67.7%, 1084 adults, 190 nymphs, 17 larvae); the American dog tick (*D. variabilis*) (n = 451, 23.7%, 448 adults, 3 nymphs); and the Pacific Coast tick (*D. occidentalis*) (n = 141, 7.4%, 140 adults, 1 nymph). These three species comprised 98.8% (1883/1905) of the ticks found on people, and we focus our analyses on these three species.

Adult *I. pacificus* ticks were more often reported biting versus crawling on people (911:172, 84.1%). A similar trend occurred for *I. pacificus* nymphs, with the majority discovered after they had attached to the human (166:22, 88.8%). Female *I. pacificus* predominated among biting *I. pacificus* adults (889:20 female:male, 97.8%).). Adult *D. variabilis* were reported more often as biting than crawling (267:175, 60.4%), while adult *D. occidentalis* were reported biting slightly less often than crawling (68:71, 48.9%). Female:male biting rates were more comparable for *D. occidentalis* (38:30 female:male, 55.8%) and *D. variabilis* (143:123 female:male, 53.8%).

Other tick species included brown dog ticks (*Rhipicephalus sanguineus* sensu lato; Nava et al., 2015) (n = 8, 5 adults, 3 nymphs), unspecified *Dermacentor* (n = 6, 2 adults, 4 nymphs), unspecified *Amblyomma* (n = 2, 2 nymphs), an *Ixodes spinipalpis* (n = 1, adult), and a spinose ear tick *Otobius megnini* (n = 1). Lone star ticks (*Amblyomma americanum*) (n = 4, 3 adults, 1 nymph) were also submitted, though we cannot confirm whether these specimens were travel-associated or not (Lang, 1999; Nieto et al., 2018).

3.2. Tick exposure in relation to human activity

Humans encountered ticks most often during recreation in natural areas, followed by peridomestic environments, and then man-made environments (Fig. 1). This pattern remained the same for all three tick species: adult western-black legged ticks (84%,13%, 2% respectively, n = 949), adult American dog ticks (81%, 15%, 4% respectively, n = 357), and adult Pacific Coast ticks (82.5%, 15%, 2.5% respectively,

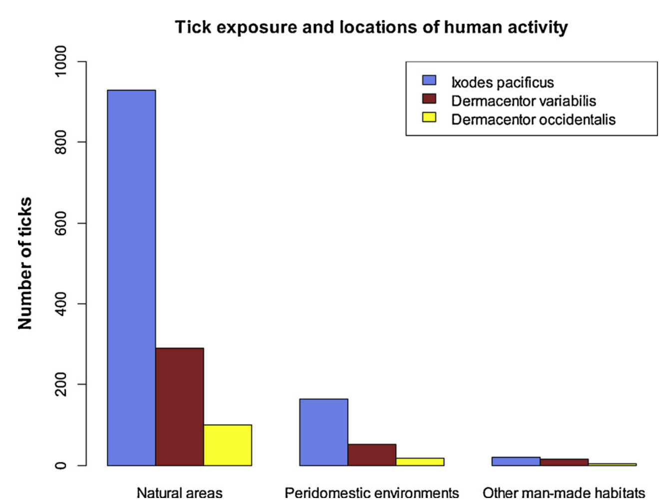

Fig. 1. Relationship between locations of human activity and exposure to ticks (all life stages included). Activities in natural areas includes hiking, dog-walking, horse-related activities, hunting, camping, fishing, biking, running, and climbing. Peridomestic exposures occur in close proximity to the home (i.e., yards and gardens), as well as dog-walking on personal lawns or within neighborhoods. Other man-made habitats include golf courses, farms, and roadsides (see Methods).

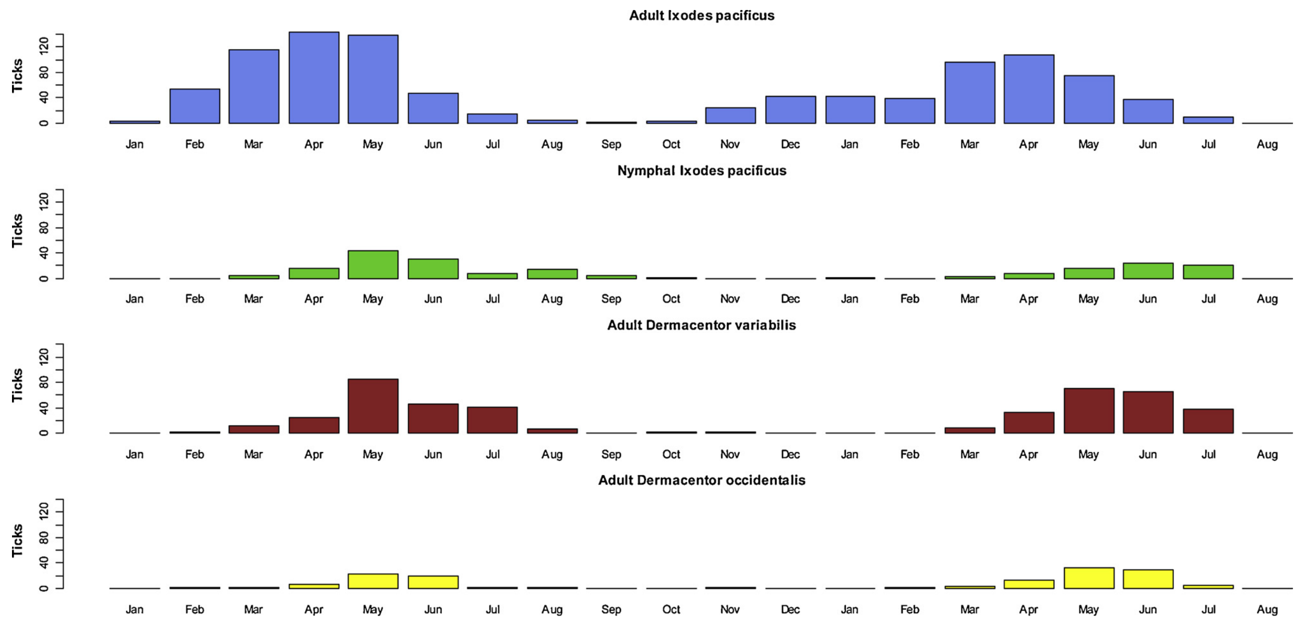

Fig. 2. Seasonal patterns of human exposure to ticks in California, from January 2016-August 2017.

n = 120). Exposure to nymphal western black-legged ticks followed the same pattern (77%, 22%, 1% respectively, n = 146). Small samples sizes of *Dermacentor* nymphs precluded analyses for this life stage.

3.3. Time of year and human exposure to ticks

Across California, western black-legged ticks were submitted in every month of the year, though numbers were low during August, September and October (Fig. 2). Low numbers of ticks were submitted in January 2016, which may have been because the program was new and not well-known; numbers were higher during January 2017. Exposures to adult western black-legged ticks increased from November, and peaked during March, April and May (Figs. 2 and 3), and encounters occurred from northern and southern California.

Nymphal western black-legged ticks increased in March and April, were most often recovered from humans in May, June and July, and declined through September (Figs. 2 and 4). Nymphs were also submitted during October and January, though in small numbers. Submissions of nymphs were predominantly from counties in northern California. Larval western black-legged ticks were recovered from humans only from February to July, peaking in May.

Human exposures to ticks of both *Dermacentor* species were infrequent during the winter, and were more common in spring and summer; peak abundance of adult *Dermacentor* spp. occurred in May, June and July (Figs. 2 and 5). *Dermacentor* nymphs were observed in July and August though in small numbers: 1 *D. variabilis* in July, 2 *D. variabilis* in August, and a single larval *D. occidentalis* in August.

May was the month of highest tick submissions, when all three life stages of *I. pacificus* are active, as well as adult *Dermacentor* spp.

4. Discussion

All three species of tick that commonly bite humans in California exhibited seasonal trends for human-tick encounters, with most exposures occurring in the late spring-early summer (March-June), though ticks were active throughout the year.

Earlier studies on seasonal tick activity in California have described surveillance for questing ticks i.e., observing or collecting ticks on vegetation or leaf-litter over time. Abundance of adult western black-legged ticks found questing on vegetation in California counties peaks

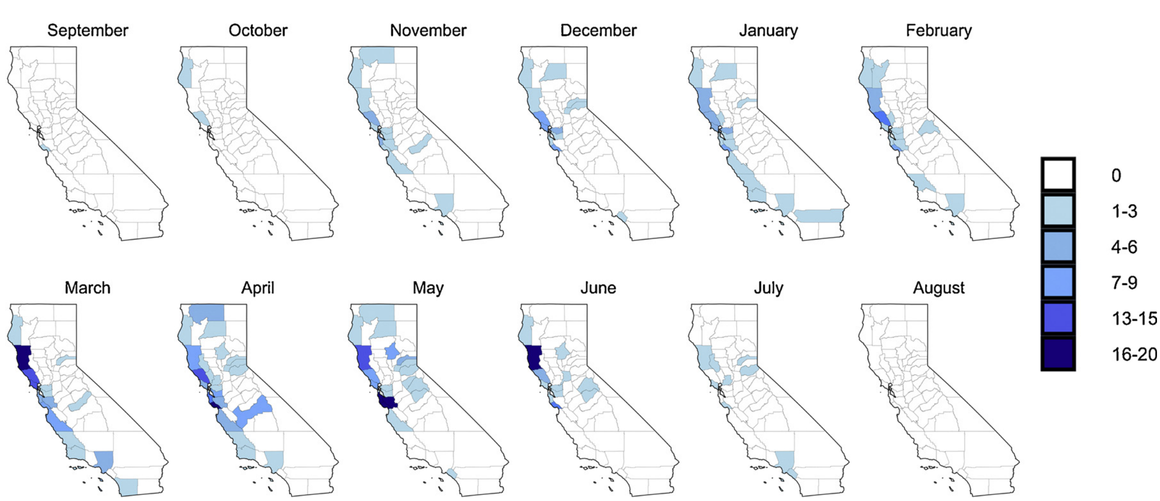

Fig. 3. Spatio-temporal patterns of human exposure to adult western black-legged ticks (*Ixodes pacificus*) in California counties, from September 2017 to August 2018.

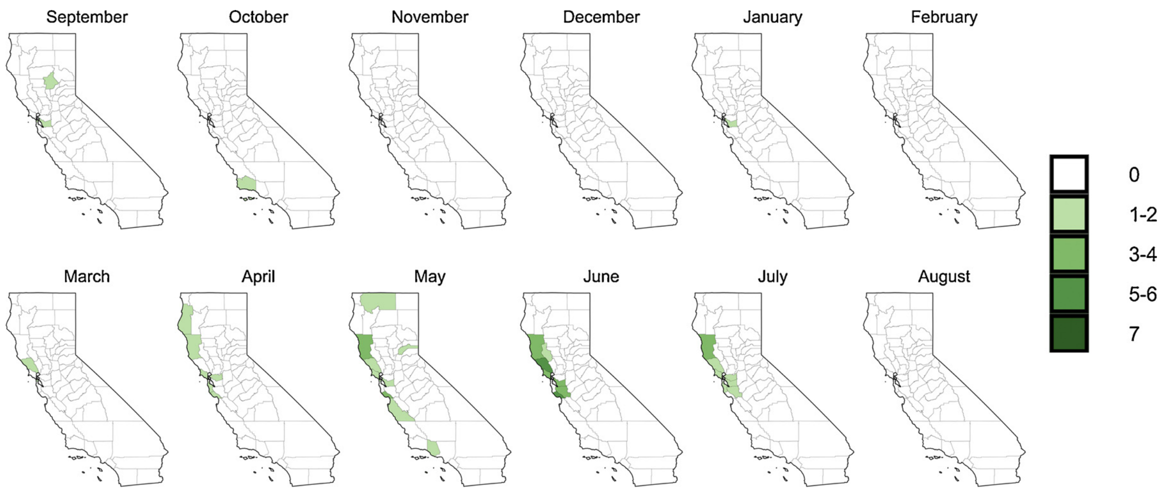

Fig. 4. Spatio-temporal patterns of human exposure to nymphal western black-legged ticks (*Ixodes pacificus*) in California counties, from September 2017 to August 2018.

in the winter (November-February) (Clover and Lane, 1995; Salkeld et al., 2014b; MacDonald and Briggs, 2016; Billeter et al., 2017). Our data differ in that they report observations of ticks actually on humans, and it is evident that there are disparities between seasonal patterns of the abundance of adult ticks in the environment and our data on human exposures. Instead, human exposure to adult western black-legged ticks peaks in March, April and May rather than during the winter (January/February). Peaks in human encounters with adult *I. pacificus* during March-May were also evident in a citizen science investigations of *Ixodes* ticks in the western United States, including California (Xu et al., 2019). This incongruity may arise because sampling of ticks questing in the environment and the human exposures were not carried out simultaneously, both spatially and temporally. For example, seasonal activity trends for western black-legged tick abundance were described using field data collected prior to 2012 (Salkeld et al., 2014b), but the human exposure data were collected in 2016–2017, as California emerged from a historic drought (Griffin and Anchukaitis, 2014). Questing activity of adult *I. pacificus* appears to be defined by the first and last rains of the season (Salkeld et al., 2014b), so the drought may have impacted the seasonal patterns of tick abundance. We also hypothesize that the discrepancy between patterns of human exposures and tick phenology is influenced by patterns of human activity: recreation and outdoor use increases as winter fades and spring and summer arrive, increasing human exposure to ticks even as tick abundance declines. Seasonal human exposure to ticks in California is therefore most likely determined by a combination of seasonal patterns of human recreation in the outdoors and underlying natural variation in the abundance of host-seeking ticks.

The disparity between tick phenology and human exposure is not observed for nymphal western black-legged ticks, which peak in questing activity and human encounters during May (Clover and Lane, 1995; Salkeld et al., 2014b; Xu et al., 2019) – presumably because human activity outdoors and tick activity overlap in this case. Likewise, exposures to *Dermacentor* adults were most abundant in May, which is when questing *Dermacentor* adults are most abundant in northern California (Kramer and Beesley, 1993; Padgett et al., 2016), though *Dermacentor* spp. peak earlier (March) in southern California (Billeter et al., 2017). Seasonality of *Dermacentor* nymphs echoed previous observed patterns of peak abundance in July and August (Padgett et al., 2016).

Adult ticks, of all three common species, were much more frequently submitted than immature ticks. The lower number of reported nymphal ticks is likely a combination of multiple phenomena, including a higher propensity to feed on larger mammals by the adult stage (Castro and Wright, 2007); differences between habitats for likelihood of exposure to the different tick life stages (Lane et al., 2013; Salkeld et al., 2015); and a lower likelihood of discovery of immature ticks because of their smaller size (Clover and Lane, 1995), and presumably the less painful bites. These observations are in agreement with other studies (Clover and Lane, 1995; Lang, 1999; Merten and Durden, 2000; Xu et al., 2019), and suggest that awareness of exposure to tick-bites, or

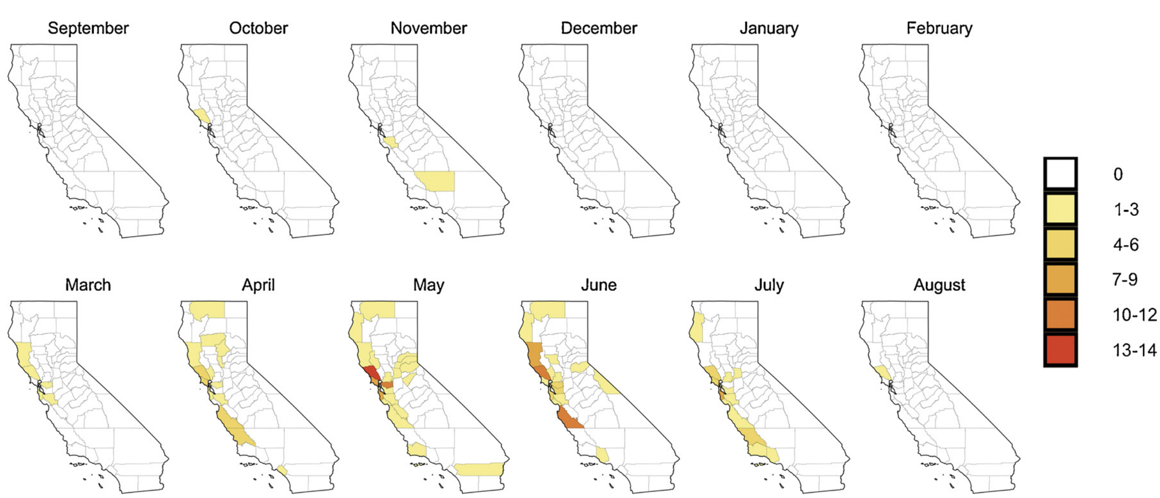

Fig. 5. Spatio-temporal patterns of human exposure to adult American dog ticks (*Dermacentor variabilis*) in California counties, from September 2017 to August 2018.

the lack thereof, should not be prejudicial in the differential diagnosis of tick-borne diseases, especially those related to pathogen transmission by nymphs.

The relationships between human activity and tick exposure in California – highest during recreational use of the outdoors – is markedly different to the northeastern US, where exposure to *Ixodes scapularis*, the black-legged tick, predominantly occurs in people's yards (86% of exposures, Mead et al., 2018; 11% of exposures occurred in forest-associated recreation, Porter et al., 2019).

Citizen science proved useful in garnering a large amount of data on human-tick encounters across California. Of course, there are weaknesses to this approach. For example, there may have been uneven knowledge of the program during its 20-month extent, and across Californian counties (Nieto et al., 2018). Furthermore, we did not collect standardized data on recent travel history, so the locations of tick exposures are ascribed simply to the submitting citizen scientist's perceived encounter location. This incurs a lack of certainty about where people are really encountering ticks, especially given that people interact with ticks during outdoor recreation and may well travel across county or state lines. With the benefits of hindsight, we argue for improved data collection on personal data (e.g., sex, age, occupation), and more detail on recent travel or activities within the likely timeframe of tick-bite or exposure, especially on the locations visited in the week preceding the discovery of the tick.

Nonetheless, a citizen science approach provides interesting data on how the idiosyncrasies of human behavior may influence patterns of tick interactions, and consequently on human exposure to tick-borne pathogens. Our data stress the wisdom of taking precautions to reduce exposure to ticks during recreational activities in California's outdoor areas. People should take particular care to search for nymphs, especially from March-July, as these small ticks are not obvious and appear to escape easy discovery. Furthermore, individuals should continue to examine themselves for 2–3 days after outdoor recreation, because as the nymphs feed and engorge they become more detectable (Lane et al., 2004).

Acknowledgements

A special thanks to all of the citizen scientists who made this study possible. We thank Nieto Lab personnel, especially Julie Wachara and Zach Barrand, for their laboratory work and data processing, and the Colorado School of Public Health for supporting SML. This work was supported by the Bay Area Lyme Foundation.

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