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Abundance of ticks (Acari: Ixodidae) infesting the western fence lizard, *Sceloporus occidentalis*, in relation to environmental factors

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Abstract. We examined the impact of environmental characteristics, such as habitat type, topographic exposure and presence of leaf litter, on the abundance of *Ixodes pacificus* ticks infesting the western fence lizard (*Sceloporus occidentalis*) at the University of California Hopland Research and Extension Center (HREC), Mendocino County, California. A total of 383 adult lizards were slip-noosed and examined for tick infestation in April and May 1998. At least 94% of the lizards were infested by ticks and at least 20% of the females and 33% of the males carried >15 ticks. This intensive utilization of western fence lizards (which do not serve as natural reservoirs for Lyme disease spirochetes) by subadult ticks, is probably the primary reason for the low prevalence of infection with *Borrelia burgdorferi* in *I. pacificus* nymphs and adults previously recorded at the HREC. Tick loads were higher on male than female lizards. Also, male lizards were generally more heavily infested in late April than in late May. The prevalence of tick infestation exceeded 88% in all habitat types but males collected in woodland and grass/woodland edges had higher tick loads than those collected in open grassland. Male lizards captured in open, exposed grassland tended to carry heavier tick loads in northern/eastern, as compared to southern/western, exposures, and when leaf litter was present.

Key words: western fence lizard, infestation, ticks, *Ixodes pacificus*, California, Lyme disease

Introduction

In California, the western black-legged tick, *Ixodes pacificus*, is the primary vector of Lyme disease spirochetes to humans (Burgdorfer *et al.*, 1985; Lane and Lavoie, 1988; Ley *et al*., 1994; Clover and Lane, 1995). Several vertebrate species, including the dusky-footed wood rat (*Neotoma fuscipes*), the California kangaroo rat (*Dipodomys californicus*) and *Peromyscus* spp. mice, serve both as hosts for subadult *I. pacificus* and reservoirs for *Borrelia burgdorferi* in northern California (Lane and Loye, 1991; Brown and Lane, 1996; Peavey *et al*., 1997). In contrast, the western fence lizard (*Sceloporus occidentalis*) and the southern alligator lizard (*Elgaria*

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multicarinata), which are some of the most important hosts for subadult *I. pacificus* (Lane and Loye, 1989; Wright *et al.*, 1998), harbor a blood-borne borreliacidal factor which render them reservoir-incompetent hosts for *B. burgdorferi* (Lane and Quistad, 1998; Wright *et al*., 1998). The prevalence of infection with *B. burgdorferi* in *I. pacificus* nymphs and adults in a given area may be directly related to the proportion of *I. pacificus* larvae and nymphs feeding on western fence lizards in that area. However, the ecological processes shaping spatial distributions of spirochete-infected *I. pacificus* ticks between and within habitats are still unclear. Studies on both the impact of environmental factors on the abundance of ticks infesting lizards and rodents, and the relative abundances of these vertebrates in different geographical areas and habitat types are needed. The primary aim of this study was to examine the impact of environmental characteristics, such as habitat, topographic exposure and presence of leaf litter, on the abundance of ticks infesting the western fence lizard.

Materials and methods

The study was conducted during April–June 1998 at the University of California Hopland Research and Extension Center (HREC), which is located in southeastern Mendocino County, California. The general climate at the HREC is Mediterranean, with cool, moist winters and dry, hot summers. For the purpose of this study we made the simple distinction between open grassland (with or without solitary trees), woodland and grass/woodland edge habitats. Tree species common in woodland areas where lizards were captured included live oak (*Quercus agrifolia* and *Q. wislizenii*), valley oak (*Q. lobata*), blue oak (*Q. douglasii*), California black oak (*Q. kelloggii*), California bay (*Umbellularia californica*) and Pacific madrone (*Arbutus menziesii*). Western fence lizards (hereinafter referred to merely as lizards) are commonly found on fallen logs and rocky outcrops at HREC from April to October (Bromwich and Schall, 1986). Male lizards are easily captured during the spring breeding season when they maintain and defend territories. Lizards were captured by slip-noosing from April 16 to 30 at eight sites, and from May 18 to June 1 at four sites. Two sampling sites were located approximately 100 m apart but clearly separated by a very steep slope. The minimum distance between the other sites was 200 m.

Adult lizards carried greater tick loads than juveniles in one previous study at the HREC (Dunlap and Mathies, 1993). Therefore, only adults, with snout-vent lengths > 60 mm, were included in this study. Males were separated from females by the presence of enlarged postanal scales. Due to time constraints the examination of tick infestation was restricted to ticks attached inside the nuchal pockets. A previous study at HREC revealed that $> 90\%$ of *I. pacificus* feeding on western fence lizards are found in the nuchal pockets (Lane and Loye, 1989). Infestations of > 15 ticks could not be correctly assessed without removing attached ticks and were therefore referred to simply as >15 ticks. A total of 236 nymphal ticks removed from 10 randomly selected lizards captured in late April at two different sites belonged to *I. pacificus*. Moreover, *I. pacificus* is the only tick species recovered from western fence lizards at HREC (Lane and Loye, 1989; Manweiler *et al.*, 1992; Dunlap and Mathies, 1993; Lane *et al*., 1995). Therefore, we assume that all ticks observed in this study were *I. pacificus*.

Environmental characteristics recorded for each spot where a lizard was caught included habitat type (grassland, woodland, or grass/woodland edge), topographic exposure, slope (flat or sloped) and absence/presence of leaf litter. Statistical tests were based on tick infestation loads grouped as low (0–6 ticks), medium (7–15 ticks), or high (>15 ticks). This provided three groups with similar numbers ($n = 80$–90) of examined adult male lizards. Differences in the prevalence of lizards infested with ticks were examined with Fisher's exact test, whereas distributions of low, medium and high tick loads were compared by the G-test (Sokal and Rohlf, 1995). Results were considered statistically significant when $p < 0.05$. Statistical analyses were carried out using the JMP® (SAS Institute Inc., Cary, NC) statistical package.

Results

Prevalence of tick infestation

In total, only 6.0% of 383 examined adult lizards had nuchal pockets free of tick infestation. The prevalence of infestation was similar for female and male lizards (92.0%, $n = 125$ and 95.0%, $n = 258$, respectively; $p = 0.26$) and for lizards captured in April and May (94.8%, $n = 249$ and 92.5%, $n = 134$, respectively; $p = 0.38$). In contrast, lizards in woodland were more likely to be infested than those in grassland (96.9%, $n = 160$ and 88.5%, $n = 104$, respectively; $p = 0.009$).

Impact of gender, sampling period, habitat type and sampling site on tick load

The overall distribution of low, medium, and high tick loads differed between adult male and female western fence lizards, with males more frequently carrying high tick loads (Fig. 1; $p = 0.02$). Moreover, males carried higher tick loads than females in grass/woodland edges (Fig. 1; $p = 0.002$), and tended to be more heavily infested in woodland ($p = 0.07$) but less so in grassland ($p = 0.28$). To avoid biases due to gender, all further analyses were based exclusively on male lizards.

Males carried similar tick loads in April and May in grassland (Fig. 2; $p = 0.39$) but higher tick loads in April than May in woodland and grass/woodland edges ($p =$

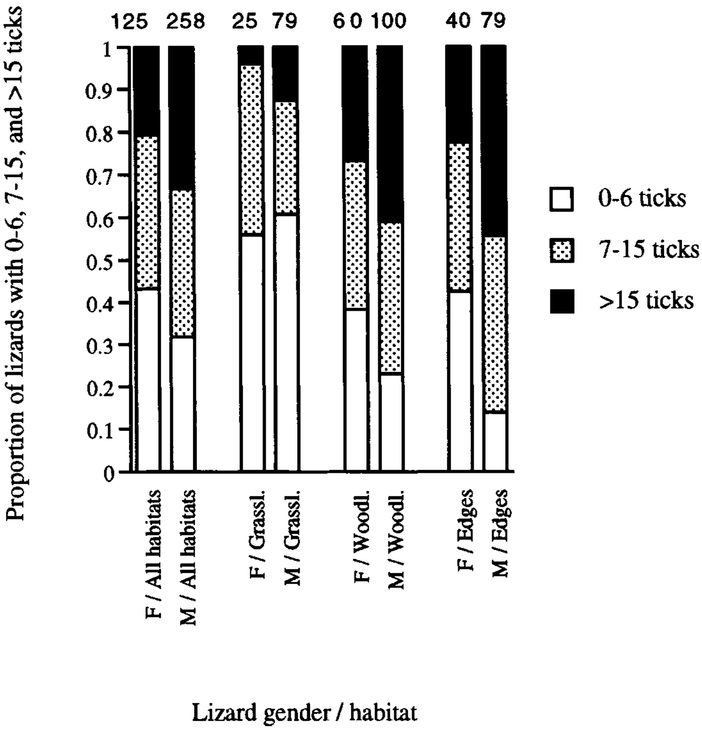

Figure 1. Tick loads on female (F) and male (M) western fence lizards in grassland (Grassl.), woodland (Woodl.), grass/woodland edges (Edges), and all habitats combined at HREC during April–May 1998. Numbers above columns denote the numbers of lizards examined.

0.01 and $p = 0.046$, respectively). Based on habitat type, tick loads were similar in woodland and grass/woodland edges in both April and May (Fig. 2; $p = 0.75$ and $p = 0.08$, respectively), whereas males captured in either of these habitats were more heavily infested than those in grassland both in April ($p < 0.0001$ in both cases) and May ($p = 0.03$ and $p = 0.002$, respectively). Likewise, males were more heavily infested in woodland and grass/woodland edges combined than in grassland in 3 of 4 sampling sites with at least 30 animals examined (data not shown; $p = 0.003$, $p = 0.01$, $p = 0.002$, and $p = 0.32$, respectively).

Considering only males captured in grassland during April, tick loads differed significantly between two sampling sites with at least 10 animals examined (James and Riley Ridge; Fig. 3; $p = 0.04$). Tick loads on males from woodland and grass/woodland edges combined, at sites with at least 15 animals examined, differed between three sites examined in April (Hagan Lake, James, and Riley Ridge; Fig. 3; $p = 0.02$), but not between three other sites sampled in May (Coop-Greenhouse, Panther Rock, and Parson’s Creek; Fig. 3; $p = 0.61$).

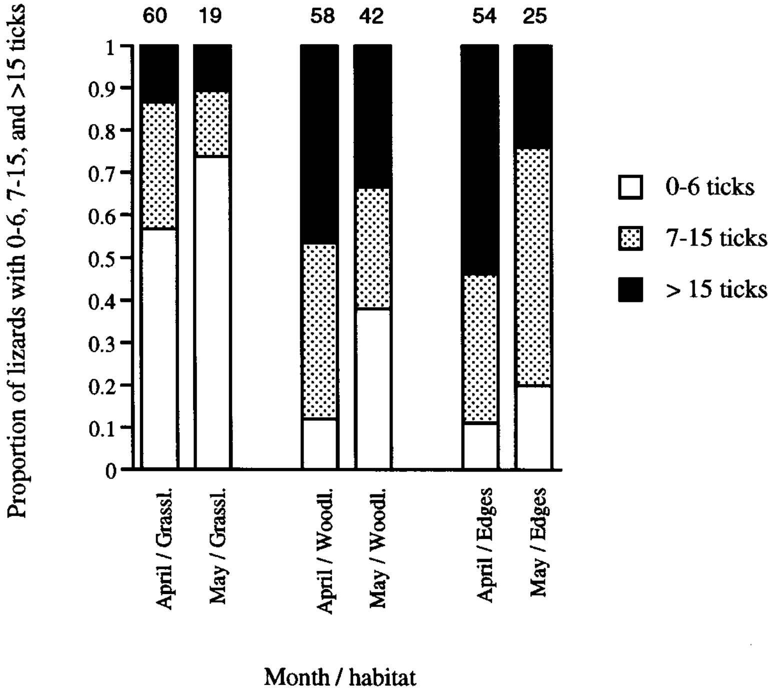

Figure 2. Tick loads on male western fence lizards in grassland (Grassl.), woodland (Woodl.), and grass/woodland edges (Edges) at HREC in April and May 1998. Numbers above columns denote the numbers of male lizards examined.

Impact of environmental characteristics on tick load

Analyses of the impact of environmental characteristics on tick loads were based on the above findings and carried out using pooled data for male lizards in April and May in grassland areas. Likewise, data for males in woodland and grass/woodland edges were pooled but April and May were treated separately. In grassland, tick loads tended to be higher for males captured in northern/eastern than in southern/western exposures but the difference was not statistically significant (Table 1; p = 0.22). In contrast, males captured in woodland-grass/woodland edges tended to have higher tick loads in southern/western exposures in April, but in northern/eastern exposures in May (Table 1; p = 0.11 and 0.30, respectively). Male lizards also tended to carry heavier tick loads when captured in areas with leaf litter present in grassland and in woodland-grass/woodland edges in May (Table 1; p = 0.11 and 0.17, respectively). Moreover, males noosed in sloped rather than flat areas tended to have higher tick loads in grassland but not in woodland–grass/woodland edges in April (Table 1; p = 0.08 and 0.77, respectively). The impact of presence/absence of

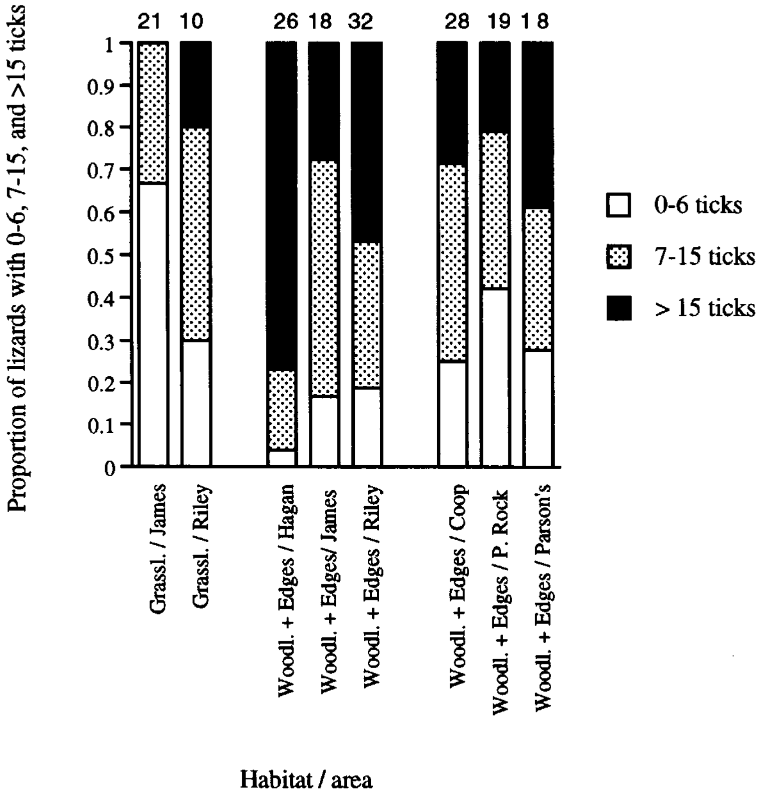

Figure 3. Tick loads on male western fence lizards in grassland (Grassl.) in April at two sampling areas (James and Riley Ridge), and in woodland–grass/woodland edges combined (Woodl. + Edges) at three areas in April (Hagan Lake, James, and Riley Ridge) and three areas in May (Coop-Greenhouse, Panther Rock and Parson's Creek) at HREC in 1998. Numbers above columns denote the numbers of male lizards examined.

leaf litter in April and flat/sloped areas in May was not tested in woodland-grass/ woodland edges due to inadequate sample sizes.

Discussion

In accordance with previous studies at HREC (Lane and Loye, 1989; Schall *et al.*, in press) male lizards generally carried higher tick loads than females in the spring. This phenomenon is probably related to behavioral differences, with males being more active and therefore exposing themselves to greater numbers of ticks than females. For instance, male western fence lizards have larger home ranges than females and, as opposed to females, actively defend their home ranges during the spring breeding season (Davis and Ford, 1983), which coincides with the peak activity of subadult

Table 1. Tick loads on male western fence lizards captured in northern/eastern (N/E) versus southern/western (S/W) exposures, areas with or without leaf litter, or in flat/sloped areas in grassland in April–May and in woodland–grass/woodland edges combined, in April and May 1998 at HREC

	Percentage (%) male lizards with 0–6, 7–15 and > 15 ticks, and number of males examined (*n*)											
	Grassland				Woodland–grass/woodland edges							
	April–May				April				May			
Trait	0–6	7–15	> 15	*n*	0–6	7–15	> 15	*n*	0–6	7–15	> 15	*n*
N/E exposure[a]	40.0	46.7	13.3	15	18.2	50.0	31.8	22	27.3	31.8	40.9	22
S/W exposure[a]	59.6	23.4	17.0	47	9.0	34.6	56.4	78	32.5	45.0	22.5	40
Litter present	45.0	30.0	25.0	20	11.3	40.6	48.1	106	25.5	43.1	31.4	51
Litter absent	66.1	25.4	8.5	59	16.7	0.0	83.3	6	50.0	25.0	25.0	16
Flat	82.3	17.7	0.0	17	16.6	41.7	41.7	12	40.0	20.0	40.0	5
Sloped	54.9	29.0	16.1	62	11.0	38.0	51.0	100	30.7	40.3	29.0	62

[a] Excluding flat transects.

I. pacificus ticks (Lane and Loye, 1989; Clover and Lane, 1995). Likewise in Europe, males of the sand lizard (*Lacerta agilis*) occupy larger home ranges than males of the common lizard (*L. vivipara*) and carry higher loads of *I. ricinus* ticks (Bauwens *et al*., 1983).

Male lizards were more heavily infested in late April than late May of 1998. This could simply have been related to higher densities of questing ticks in April than May. However, the density of questing nymphs in leaf litter at HREC was similar in late April and late May 1998 (L.T.-E. and R.S. Lane, unpublished data). Alternatively, male lizards may have been more active in April than May. The maximum daily temperatures at HREC were higher during the sampling period in April than in May (averages of 18.1 and 13.7 °C, respectively; C.E. Vaughn, University of California at Davis, unpublished data).

Questing *I. pacificus* nymphs can readily be collected from leaf litter, but not from grassland, by dragging a cloth over the ground, whereas adults are frequently found in grassland using this method (Clover and Lane, 1995; Lane, 1996). However, our findings that 88% of all lizards collected in grassland were infested by subadult ticks and that 39% of the males captured in this habitat carried > 6 ticks demonstrate that subadult *I. pacificus* ticks commonly occur in this habitat type. The home ranges of both breeding and non-breeding adult male western fence lizards are small, generally $< 80\ m^2$ (Davis and Ford, 1983). Thus, males collected in grasslands probably also acquired their ticks in grasslands. The discrepancy between the results of cloth-dragging *versus* examination of lizards in grassland probably results from the fact that *I. pacificus* subadults quest primarily within leaf litter or below the soil surface, and avoid ascending the vegetation (Lane *et al.*, 1995).

Lizards collected in woodland or grass/woodland edges were more likely to be infested with ticks and carried heavier tick loads than lizards in grassland. Similarly, the southeastern five-lined skink (*Eumeces inexpectatus*) is more frequently infested with *I. scapularis* ticks in brushy or forested habitats than in open fields (Apperson *et al*., 1993). Subadult *I. pacificus* ticks are sensitive to desiccation (Peavey and Lane, 1996), thus the mortality of developing or questing subadult ticks may be higher in open, exposed grassland than in woodland. Alternatively, lizards may simply spend more time in microhabitats where they encounter *I. pacificus* ticks in forested areas. In Australia individual sleepy lizards (*Tiliqua rugosa*) with high tick loads one year tended to have high tick loads the next year, which suggests that such individuals regularly revisit well-protected refuges where ticks enjoy a sheltered microclimate and frequent exposure to hosts (Bull and Burzacott, 1993). Further, presence of endoparasites could also affect lizard behavior and, thus, the degree of exposure to ticks. For instance, male western fence lizards infected with *Plasmodium mexicanum* spend less time engaging in social activities, such as chasing other males, than uninfected males (Schall and Sarni, 1987; Schall and Houle, 1992). We conclude that further studies on spatial activity patterns of western fence lizards in relation to both climatic conditions and the micro-distribution of questing subadult *I. pacificus* ticks in different habitat types are needed to elucidate the factors determining tick loads of western fence lizards.

Even within habitat types tick loads differed for male lizards captured at different sampling sites. Several factors may contribute to these differences. For instance, topographic exposure may be more likely to impact abundance of questing ticks as well as lizard activity in open grassland rather than in woodland. Also, absence or presence of leaf litter may impact loads of subadult *I. pacificus* ticks, which are sensitive to desiccation, on lizards. Higher tick loads in grassland at Riley Ridge than at James (Fig. 3) could have been related to a higher proportion of lizards captured in areas with leaf litter present at Riley Ridge than at James (50, as compared to 10%). In contrast, the difference in tick loads between males captured in woodland-grass/woodland edges at three sites in April could not be clearly explained by any of the environmental factors measured. However, factors not evaluated by us may have resulted in site-related differences in the abundance of questing subadult *I. pacificus* ticks. For example, the utilization of these sites by Columbian black-tailed deer (*Odocoileus hemionus columbianus*), which is a primary host for adult *I. pacificus* at HREC (Westrom *et al*., 1985), may have differed.

Of the 383 lizards examined at the HREC, at least 94% were infested by subadult ticks and 29% by >15 ticks. Previous studies at HREC have demonstrated that both prevalence and intensity of infestation by *I. pacificus* ticks are considerably greater on lizards than on *Peromyscus* spp. mice (Lane and Loye, 1989, 1991). This intensive utilization of the western fence lizard, which is reservoir-incompetent for *B. burgdorferi* (Lane and Quistad, 1998), is probably the primary reason for the low prevalence of infection with *B. burgdorferi* in *I. pacificus* nymphs (0–5%) and adults (0–2%) at the HREC (Burgdorfer *et al*., 1985; Lane and Lavoie, 1988; Tälleklint-Eisen and Lane, 1999). However, infection prevalences in *I. pacificus* nymphs considerably higher than at HREC have been recorded from other areas in northern California (i.e., 10–41% in Mendocino and Placer counties; Clover and Lane, 1995; Wright *et al*., 1998; Tälleklint-Eisen and Lane, 1999). Thus, it is still unclear to what extent lizards serve to decrease the intensity of transmission of *B. burgdorferi* at the *I. pacificus*–host interface in Mendocino County or northern California as a whole. We conclude that more studies on the inter-relationship of *B. burgdorferi*, potential tick vectors and vertebrates are needed in high risk habitats for Lyme disease, such as woodlands with abundant leaf litter.

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