Copeia, 1993(4), pp. 1045–1048

Effects of Nymphal Ticks and Their Interaction with Malaria on the Physiology of Male Fence Lizards

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Ectoparasites infest many lizard species, but the physiological consequences of infestation in free-living lizards have not been studied. We examined male western fence lizards, *Sceloporus occidentalis,* infested with ticks, *Ixodes pacificus,* in northern California. Many lizards in this population were also infected with malaria, *Plasmodium mexicanum.* We found that the effects of nymphal ticks on blood composition and body condition (relative body weight) depended on the age of the lizard host and whether the lizard was also infected with malaria. Adult male lizards, but not juveniles, infested with ticks had lower hematocrits than uninfested lizards. Although the reduction in hematocrit that accompanies the mean level of tick infestation probably does not substantially affect the lizards, heavy infestations (>5 ticks per lizard) may significantly limit the aerobic capacity and behavior of the lizard host. Lizards parasitized with both ticks and malaria had significantly lower body condition than lizards with one or neither parasite.

MANY free-living lizards carry ectoparasites, and, when infested lizards are brought into captivity, they sometimes experience poor health and survival (Mader et al, 1986). However, captive lizards often host unnaturally high levels of infestation because captivity typically facilitates transmission between hosts and alters the host's immune system and behavior. Several studies have examined the histopathology (Golberg and Bursey, 1991), prevalence (Lane and Loye, 1989), and competition (Andrews et al., 1982) of ectoparasites on free-living lizards; but the physiological consequences of ectoparasitic infestation on lizards in the wild are unknown. The effects of multiple parasites on lizard physiology has also not been studied. Here we discuss the influence of ticks, *Ixodes pacificus,* and their interaction with malaria protozoans, *Plasmodium mexicanum,* in disrupting the physiology of male western fence lizards, *Sceloporus occidentalis.*

In northern California, fence lizards carry the larval and nymphal stages of *I. pacificus* which attach primarily in an area just posterior to the external ear (the lateral nuchal pocket). In the spring, ~50–90% of the lizards carry *I. pacificus* (Lane and Loye, 1989). Many lizards (20–50%) in this population are also infected with malaria, *P. mexicanum.* Schall and his colleagues (Schall, 1990) have described the infection dynamics and many physiological pathologies associated with malaria at this site. In brief, infected lizards have an impaired ability to transport oxygen, store fat, and reproduce compared with uninfected lizards. In our study, we concurrently examined the virulence of both parasites. We found that ticks have very different effects from malaria on *Sceloporus* and that some pathologies are only expressed when the lizard host is parasitized with both ticks and malaria.

Methods

We captured male lizards in the oak woodlands of the University of California Hopland Field Station near Hopland, California, ~140 km north of San Francisco. We conducted this study in June 1990 as a part of a project examining the effects of parasitism on the male reproductive physiology of *S. occidentalis.* Schall has studied lizard malaria at this site for many years and describes the site and the biology of *Sceloporus-Plasmodium* interactions elsewhere (Schall, 1983).

We caught male lizards by noose and collected blood (~150 μl) from the orbital sinus within 1 h of capture. After bleeding in the field, lizards were brought into the lab to measure their size (snout–vent length in mm), weight (g), and the abundance of ectoparasitic ticks *I. pacificus* and blood-borne *P. mexicanum.* The lizards carry both larval and nymphal stages of *Ixodes.* However, in this study we counted only nymphal ticks. For all lizards, we made smears from a drop of blood from toe clips and stained the smears with Giemsa. The slides were viewed under 1200× to determine whether the animal was infected with *Plasmodium* and, if so, the number of infected cells per 10,000 red cells. The hematocrit (% packed cell volume) was

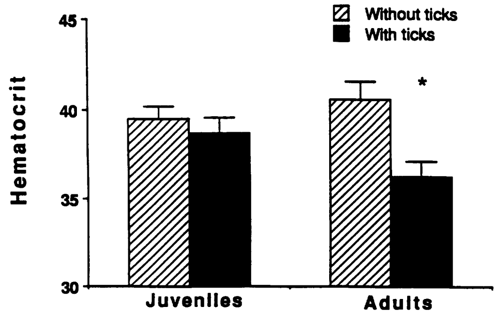

Fig. 1. The hematocrit (mean± SE) of juvenile and adult male fence lizard without (striped bar) and with (solid bar) black-legged ticks. Adults with ticks have significantly lower hematocrits. Data from lizards infected with malaria are included because malaria does not influence hematocrit.

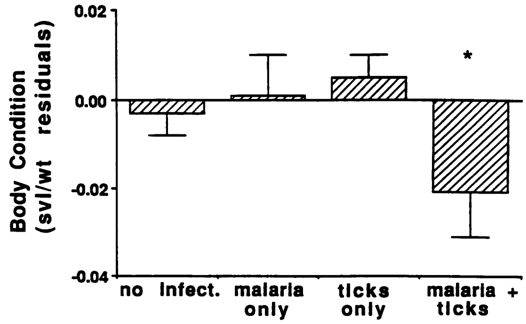

Fig. 2. The body condition (mean ± SE) of male fence lizards without infection, with malaria, with ticks, or with both malaria and ticks. Body condition is estimated by the residuals of the log SVL vs log weight regression. Lizards with both malaria and ticks are significantly lighter for their size than uninfected lizards or lizards carrying only one species of parasite. A lizard with a body condition of −0.02 is approximately 0.5 g lighter than an average lizard. Data from juveniles and adults are combined since age does not affect body condition.

measured from blood centrifuged in the lab at ~1500 rpm for 10–15 min. We returned all lizards to the field within 1–2 days. All lizards were marked prior to release so that no lizard was captured more than once.

We estimated the body condition of the animals by regressing log body weight on log snout-vent length (SVL) and calculating the residuals. To analyze the data, we used a three-way ANOVA with hematocrit and body condition (log SVL/log weight residuals) as dependent variables and age, presence of ticks and malaria as covariates. We used size to distinguish between juveniles (<60 mm SVL) and adults (≥60 mm) based on data collected by Schall (1983).

Results

Of 173 animals we examined, 42.7% were parasitized with nymphal ticks only, 12.1% with malaria only, and 8.6% with both parasites. The observed frequency of multiple parasitism (8.6%) did not differ significantly from the expected frequency (10.6%), based on the frequency of each parasite ($P = 0.29$). Juvenile (<60 mm) and adult (≥60 mm) lizards were equally likely to carry ticks, but infested adults tended to host more ticks (adults = 3.6 ± 0.4 ticks, juveniles = 2.2 ± 0.2 ticks; mean ± SE; $P = 0.003$). A greater proportion of adult lizards (28%) than juveniles (13%) was infected with malaria, but parasitemia (number of infected cells per 10,000 red blood cells) was lower in adults (48 ± 10) than in juveniles (91 ± 20; $P = 0.019$).

Adult lizards parasitized by ticks had significantly lower hematocrits than uninfested lizards (40.6 ± 1.0 vs 36.2 ± 0.9; $P = 0.004$; Fig. 1). Hematocrit correlated negatively with number of ticks ($r^2 = 0.12$; $P = 0.004$). The hematocrit of infested juveniles was not lower than infested juveniles and did not correlate with the degree of tick infestation ($P = 0.17$). Malarial lizards had equal hematocrits to uninfected animals.

When lizards were parasitized by either *Ixodes* or *Plasmodium* alone, their condition (log SVL/log wt residuals) was equivalent to animals with neither parasite, but animals hosting both parasites were significantly lighter for their size ($P = 0.035$; Fig. 2). Animals with multiple infections weighed ~0.5–1.0 g less than animals with one or neither parasite.

Discussion

We found that male fence lizards, *S. occidentalis,* infested with nymphal black-legged ticks, *I. pacificus,* had significantly altered blood composition and body condition. However, the virulence of the ticks depended largely on the age of the host and the presence of the malarial parasite. In particular, tick-infested adult lizards had significantly reduced hematocrit, but juveniles were unaffected (Fig. 1). Lizards parasitized by both ticks and malaria had relatively low body weight for their size, whereas lizards with ticks or malaria alone did not appear affected (Fig. 2).

Ticks induce anemia in many mammals (Gemmel et al., 1991; O'Kelly and Seifer, 1970; Rechar et al., 1980), but the mechanisms by which they reduce hematocrit are not clear. Ticks feed by inserting their hypostome into the skin, reaching as far as the dermis (Golberg and Bursey, 1991). After sucking up blood, most ticks concentrate the red cells and regurgitate a portion of the plasma back into the host. Some ticks produce proteins, hemolysins, in their saliva that lyse the hosts' red cells when regurgitated (Arthur, 1961). Many ticks also transmit viruses, bacteria, and protozoans in their saliva. Thus, ticks could alter the red cell concentration of their hosts in at least three ways: (1) directly reducing the hematocrit by consuming their red cells, (2) releasing a toxin that lyses the hosts' red cells, or (3) transmitting pathogens that secondarily lyse red cells or interrupt hemopoiesis.

The first of these mechanisms producing anemia has been discounted in most mammals because ticks consume relatively little blood compared to the total blood volume of the host. However, for lizards weighing only 5–15 g, the quantity of extracted blood may not be trivial. A fully engorged nymphal *I. pacificus* weighs ~4 mg (KDD, unpubl. data), and, if ~90% of its maximal weight is derived from the host (Hayashi and Hasegama, 1983), it consumes ~3.6 mg of blood. Assuming an adult (12 g) lizard has ~275–375 mg of red blood cells (Lillywhite, 1984; Thorson, 1968), it would require 8–10 nymphal ticks to lower the hematocrit by 10%, the mean decrement we observed in infested adult lizards. Although this is higher than the mean 3–4 nymphal ticks we found on adults in the field, we conducted our survey in June, several months after the period of peak tick abundance. In addition, our count of ticks did not include larvae, each of which can consume ~0.3 mg of blood (Hayashi and Hasegama, 1983). Lane and Loye (1989) report that 3–10 larvae and 12–18 nymphs typically infest *Sceloporus* in the months before June. Considering the total number of larvae and nymphs prior to our survey, the blood loss resulting from consumption by ticks appears sufficient to explain the lower hematocrit in adult lizards, and it may not be necessary to invoke the action of a toxin produced by the tick or an accompanying pathogen. However, it is not known how quickly lizards can replace their red cells after blood loss to ticks, and such information is necessary to fully assess the cumulative effect of tick infestation.

It is not clear why juveniles are relatively unaffected by the blood loss. They have substantially fewer red blood cells (120–160 mg) and, on average, only 1–2 fewer ticks. Using the arguments above, one would expect that ticks would be more virulent to juveniles than adults. Perhaps juveniles become parasitized later in the season or produce red cells more quickly in response to blood loss (Boggs, 1988).

An average tick infestation in an adult lizard is associated with a 10% reduction in the hematocrit. If an equivalent decline in hemoglobin concentration accompanies the mean 10% decline in hematocrit, most tick-infested lizards could deliver oxygen at ~93% the maximal rate (Schall et al., 1982). We cannot determine from this study whether a 7% decline in aerobic capacity affects the survival or behavior of adult lizards. However, Schall found that *Sceloporus* rarely exercise their full aerobic capacity in the wild, except perhaps during courtship or territorial conflict (Schall and Dearing, 1987; Schall and Sarni, 1987). It, thus, seems unlikely that a 7% decline in maximal oxygen transport would significantly limit their behavior.

Nevertheless, individual lizards vary considerably in the number of ticks they host (1–32 larvae and 1–67 nymphs; Lane and Loye, 1989). Heavy infestations (>5 nymphs per lizard) reduce hematocrit by as much as 40% and, thus, may substantially limit the lizard's social behavior. Weak tick infestations may disrupt hearing function when they attach at the periphery of the tympanic membrane (Golberg and Bursey, 1991) or by transmitting bacterial or protozoan infections (Camin, 1948).

Less severe tick infestations may also harm their hosts by exacerbating the effects of other parasites. For example, although weak tick infestations alone probably have relatively minimal consequences for lizard hosts, they may further impair the delivery of oxygen if the hosts are also infected with malaria. Malarial lizards have an excess of immature red blood cells, which typically reduces hemoglobin concentration by 25% and running stamina by 20% (Schall et al., 1982). An additional reduction in hemoglobin by blood loss to ticks would further limit the lizards' capacity for aerobic behavior. The combined influence of ticks and malaria on oxygen delivery may explain in part our finding that male lizards with both parasites have lower body condition. Territory establishment and maintenance sometimes require considerable aerobic activity, and lizards with both parasites may be unable to hold territories that have abundant food.

Our study describes pathologies in naturally parasitized male lizards that have been repeatedly shown in experimental infestations of many other species (Gemmel et al., 1991; O'Kelly and Seifer, 1970; Rechar et al., 1980). However, we have not demonstrated a causal relationship between infestation and the observed pathologies. It is possible, for example, that poorly nourished animals (lower body condition) are more likely to become infested with these parasites. Although nutritional state can influence the immunity of reptiles (Kollias, 1984), very little is known about how lizards may protect themselves from or rid themselves of ectoparasites or malaria.

Acknowledgments

We thank D. Whitaker, B. Sendak, and M. Mishra for their help collecting lizards and the staff of Hopland Field Station for accommodating our research on their property. J. Schall viewed the blood smears for malarial detection. R. Lane and E. Holmes provided helpful comments on the manuscript. This work was supported in part by grants from the National Science Foundation to J. Schall (BSR-8806235) and J. Wingfield (DPP-9023834), Sigma Xi, the Theodore Roosevelt Fund of the American Museum of Natural History, and the Institute for Environmental Studies, University of Washington to KDD.

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