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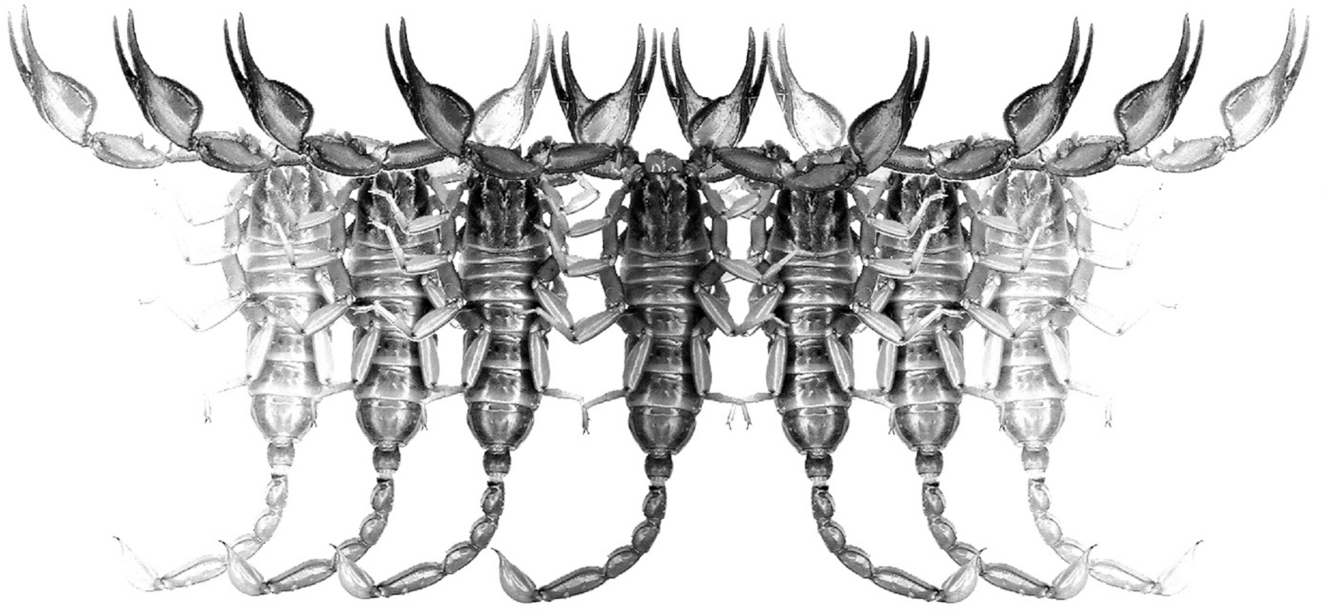
Occasional Publications in Scorpiology



Influence of environmental factors on surface activity of *Paruroctonus marksi* (Scorpiones: Vaejovidae) in the Mojave Desert

Zia Nisani, Destiny Frederick, Alejandro Garcia-Plascencia, Daian Lopez, Robert Miller & Linhsan Trinh-Nguyen

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Influence of environmental factors on surface activity of *Paruroctonus marksi* (Scorpiones: Vaejovidae) in the Mojave Desert

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Summary

Many environmental factors may influence the activity pattern of scorpions in arid ecosystems. We investigated the seasonal variations of *Paruroctonus marksi* scorpion activity in the Mojave Desert (California, USA). Black light surveys were carried out within two 100 ×100 m plots from August 2017 to September 2018. The majority (85%) of scorpions were found in open areas compared with being in vegetation. The presence of *P. marksi* was positively correlated with both water vapor pressure and soil temperature, while moon illumination had no significant effect on *P. marksi* foraging behavior. Scorpions might be using humidity as an indicator of prey abundance and since they are not visual hunters, and moonlight does not affect their surface activity possibly due to lack of visual hunters in the study site.

Introduction

Scorpions are common and ecologically important arthropods in arid and semi-arid ecosystems of the world (Jiménez-Jiménez & Palacios-Cardiel, 2010; Nime et al., 2014; Lira et al., 2018). These solitary predators are present on all continents except for Antarctica (Sissom, 1990). They primarily feed on terrestrial arthropods, including other scorpions, and they, in turn, are preyed on by other organisms, especially by vertebrates (Polis & McCormick, 1987; Polis et al., 1981). Scorpions owe their extensive distribution and high abundance to the various adaptations they have, in order to survive in a harsh desert climate (Hadley, 1974; Stockmann, 2015; Sridhara et al., 2016).

Seasonal and daily patterns of scorpion activity are influenced by both biotic (presence of predators, prey, or potential mate) and abiotic factors (Yamaguti & Pinto-da-Rocha, 2006; Dionisio-da-Silva et al., 2018). Environmental factors such as soil, topography, hydrology, temperature, and illumination have been shown to influence scorpion activity (Skutelsky, 1996; Yamaguti & Pinto-da-Rocha, 2006; Nime et al., 2013). Many environmental factors, such as temperature, wind, and illumination, may affect a scorpion's efficiency in performing various activities, or affect them indirectly by influencing their predatory efficiency, the behavior of their prey, or intra- and interspecific interactions (Skutelsky, 1996).

Most scorpions detect prey by sensing air and surface vibrations rather than vision (Fleissner, 1977; Brownell, 1979), so moonlight is not likely to have a direct effect on their surface activity (such as foraging). As such, moonlight might affect their behavior indirectly through changes in predation risk or prey availability (Tigar & Osborne, 1999; Skutelsky, 1996). For example, Skutelsky (1996) showed that adult *Buthus occitanus israelis* (Shulov & Amitai, 1959) were less active on moonlit nights than dark nights and tended to ambush under bushes when moon illumination was high. He also concluded that the adult scorpions that do forage under moonlit conditions, tended to have relatively low energy reserves (as determined by low mass-to-size ratio).

In the present study, we investigated the seasonal variation in surface activity of *Paruroctonus marksi* (Haradon, 1984) (Vaejovidae) in Mojave Desert, Lancaster, California, during a period of 14 months. The main goal of this study was to evaluate the influence of moonlight and other factors, such as temperature, relative humidity, and wind speed, on the surface activity of these scorpions. Small scorpions and younger age classes of larger species have been known to forage both on land and on plants by climbing into shrubs and herbs (McReynolds, 2008). One possible explanation for scorpions foraging on shrubs and plants is to minimizes predations and cannibalism (Polis, 1980; Polis & McCormick, 1987). Thus, we hypothesis that during period of higher moon illumination, we expect to find more scorpions in shrubs and under cover compared to darker nights.

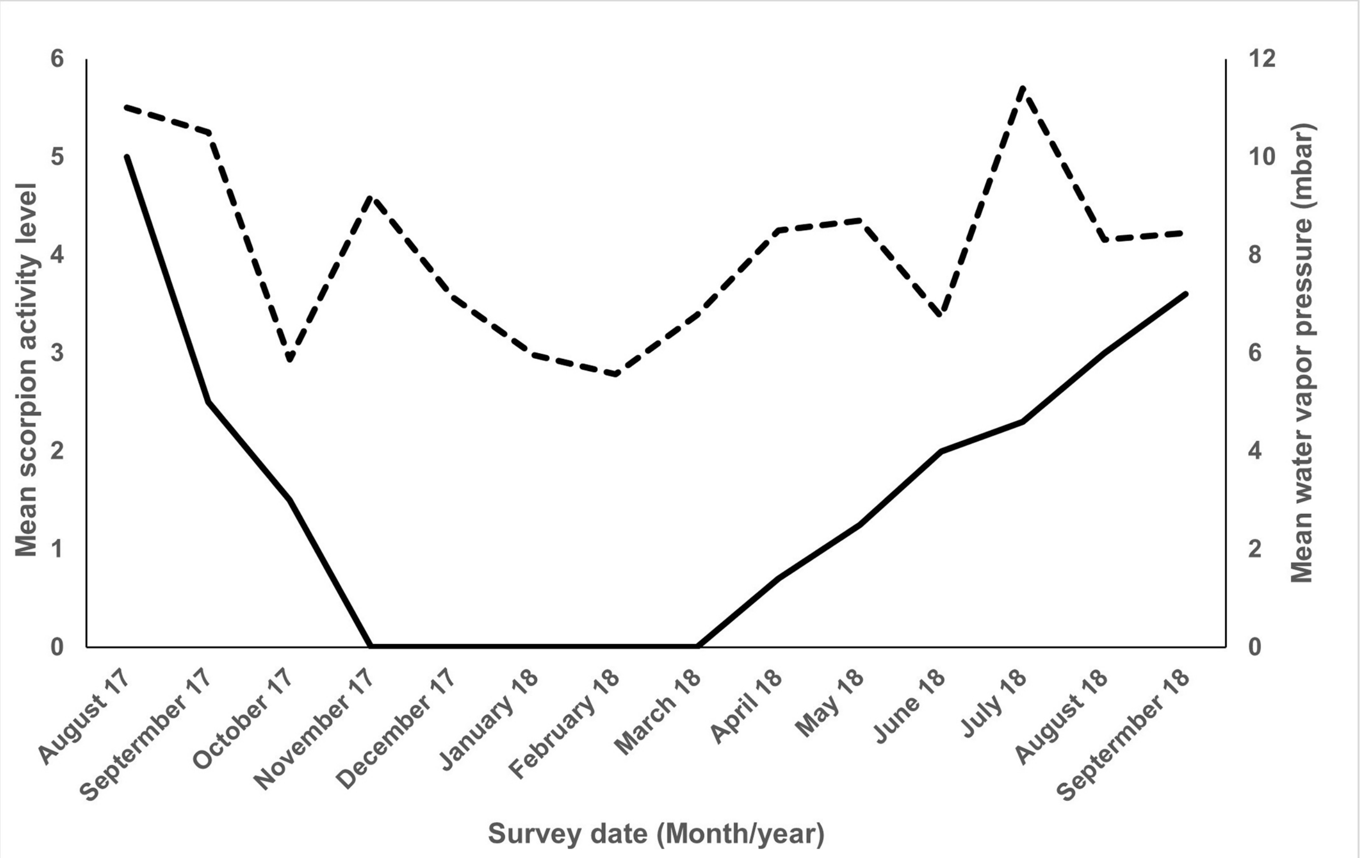

Figure 1. The mean abundance of scorpions (solid line) and water vapor pressure (dashed line) from August 2017 to September 2018.

Materials and methods

Study Site. The Mojave Desert includes approximately 117,000 km^2 of southern California, Nevada and northwestern Arizona. Its boundaries are defined by its vegetation, and mostly the presence of Joshua Trees (*Yucca brevifolia*). Our study site was an undeveloped area located in Lancaster, CA. The dominant vegetations of research plots were Creosote (*Larrea tridentata*), Big Galleta (*Hilaria rigida*), Blackbrush (*Coleogyne ramossissima*), and few Joshua Trees (*Y. brevifolia*). There were two plots (A: 34°39'14.7"N 118°11'40.0"W; B: 34°39'18.4"N 118°11'52.4"W) measuring 100 ×100 m separated by 200m, and they were sampled between 8 - 10 times in a month (except for wintertime they were sampled 3 times a month December 2017 to February 2018).

Observational Methods. The study was conducted from August 17, 2017, to September 22, 2018. The census in each plot was initiated 2 hours after sunset and terminated after 3 hours using black light and was conducted independently by a two-person team, resulting in 6 survey hours for each plot every census. We recorded the above-ground activity level (defined as the number of scorpions above ground) and their location. If the scorpion was in an open area (rather than in any cover), its distance to the nearest cover (i.e. vegetation, rock, or anything scorpion can take refuge in) was measured to the nearest millimeter.

We measured air temperature, relative humidity, and wind velocity at 150 cm (above ground) and 1.5cm (ground level), using Vane Traceable Anemometer Pens. Soil temperature was measured using Taylor® Soil Thermometer by gently sticking it into soil next to the scorpion. Finally, the moon illumination was recorded using "Time and Date AS" website (timeanddate.com/moon/) and a meteorological table was used to calculate water vapor pressure (WVP) from the measurements of relative humidity and temperature above ground.

Statistical Analysis. The relative influence of environmental factors on scorpion activity was analyzed using multiple regression analysis. The dependent variable was the "activity level' (number of scorpions seen above ground in the plot), and explanatory variables were water vapor pressure, ground-level wind velocity, soil temperature, moon illumination, and ground-level relative humidity. The standard partial regression coefficient was used in the presentation of results (Skutelsky, 1996; Zar, 1996). There was no significant difference between air temperature above ground and soil level (t(120) = 0.264, p = 0.792), wind velocity above and ground level (t(120) = 1.86, p = 0.065), and relative humidity above and ground level (t(120) = 0.01, p = 0.991). Thus, the regression was only performed with ground-level data for temperature, velocity, and relative humidity. Finally, a correlation analysis was conducted to see if water vapor pressure and moon illumination affected the distance from cover.

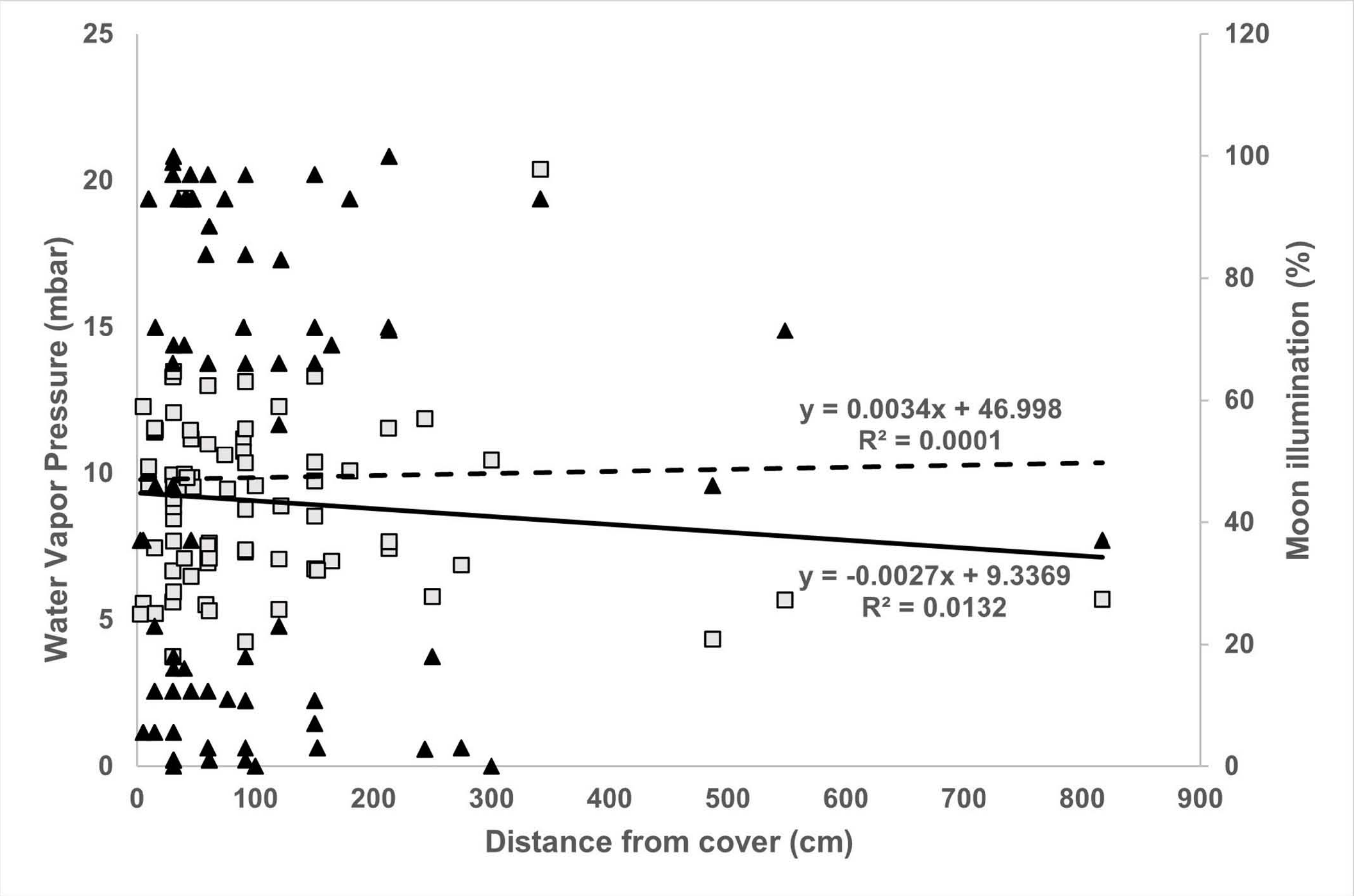

Figure 2. Distance of adult scorpions from cover in relationship to water vapor pressure (grey squares) and moon illumination (dark triangles). The solid and dashed lines represent the trend line for water vapor pressure and moon illumination respectively.

Results

Between August 2017 and September 2018, a total of 60 censuses were conducted, of which 10 days of survey were overcast, but that did not play any role in scorpion presence or absence. The number of active scorpions increased with water vapor pressure (Standard coefficient = 0.248, N = 61, $p = 0.028$) and soil temperature (Standard coefficient = 0.096, N = 61, $p = 0.045$), with largest surface activity being during July to September (Fig. 1). The water vapor pressure was significantly ($t(30) = 2.96$, $p = 0.004$) higher (9.23 ± 0.33 mbar) when scorpions were found compared to when they were not found (7.41 ± 0.4 mbar).

The majority (85%) of scorpions above ground were in open areas with only 15% associated with vegetation. When in an open area, the mean (±SE) distance to cover was 106 ± 14.6 cm. This distance was not influenced by water vapor pressure (Fig. 2, $r = 0.115$, $p = 0.309$) nor moon illumination (Fig. 2, $r = 0.057$, $p = 0.633$).

Discussion

In the present study, the scorpions were mostly active in warm and humid nights, however soil temperature could have also played a minor role in their activity level. There was a positive relationship between the number of scorpions detected above ground and water vapor pressure. There are two possible explanations for this observation. The first is that humidity has a direct effect on the individual's dehydration rate. Bradley (1988) reported that *Paruroctonus utahensis* (Williams, 1968) activity was positively related to water vapor partial pressure. However, this correlation disappeared when daily residual analysis was conducted on the data, suggesting that this was a seasonal effect and not a proximate daily response. Thus, desiccation avoidance is not a viable explanation for low surface activity when water vapor partial pressure is low. Second, on dry nights, the prey abundance might be less than humid nights. Skutelsky (1996) also found a significant positive relationship between water vapor pressure and the number of *Buthus occitanus israelis* (Shulov & Amitai, 1959; now *B. israelis*) (Buthidae) active above ground, but he speculated that these scorpions use water vapor pressure as an environmental cue to evaluate prey availability. We believe that the second explanation holds true for this study, as studies have shown that arthropod abundance increases with an increase in the air moisture (Tigar & Osborne, 1997). Since scorpions have water-resistant cuticles and are relatively resistant to desiccation (Toolson & Hadley, 1978), their foraging during humid nights might be tied-in to prey abundance and not desiccation prevention.

Most scorpions in our study were found to be motionless in open areas. Similarly, Nime and her colleagues studied the microhabitat use in the scorpion *Brachistosternus ferrugineus* (Thorell, 1876) (Bothriuridae) and found that they spent most of their time on the soil in ambush position (Nime et al. 2016). However, a small percentage were also found to be in vegetation. This foraging on shrubs has been explained as a predator avoidance by scorpions (Polis, 1980; Polis & McCormick, 1987), and a way to exploit prey availability on plants (Skutelsky, 1996; Brown & O'Connell, 2000; McReynolds, 2008; Pinero et al., 2013). However, we did not control for size and sex of the scorpions, thus our interpretations should be limited to adult scorpions because the probability of findings scorpions in shrubs is inversely related to scorpion size (McReynolds, 2012; Piñero et al., 2013; Sanchez-Piñero & Urbano-Tenorio, 2016). Smaller scorpions are more likely to forage in or around shrubs, than larger scorpions (Sánchez-Piñero & Urbano-Tenorio, 2016). Since peak number of scorpions observed in this study correspond to reported mating seasons (Polis & Farley, 1979), this might explain why more scorpions were found in open areas.

Some studies have suggested that scorpions reduce foraging activity as a response to moonlight (Hadley & Williams, 1968; Skutelsky, 1996; Tigar & Osborne, 1999). However, in our study, moon illumination was not a factor in determining if scorpions will be found foraging in open areas or shrubs. Similarly, others have also not detected any correlations between variations in levels of moonlight and foraging behavior in some *Paruroctonus* species (Polis, 1980; Bradley, 1988). Moonlight is not likely to have a direct effect on scorpions' foraging behavior, but rather an indirect effect through reducing predation. In our study site, due to lack of mammalian and avian predators (personal observations), the visual predators might not be a factor. This might explain the lack of moonlight influence on the activity level of *P. marksi*.

In our study, the nocturnal surface occurrence peaked around August and September, with no occurrence from November to March (winter months). These results are in agreement with previous studies. Polis and Farley (1979) demonstrated that in *Smeringurus mesaensis* (Stahnke, 1957; then placed in *Paruroctonus*) (Vaejovidae) most of the mating occurred between August and September with some mating occurring as early as May and as late as October. Environmental factors such as water vapor pressure and soil temperature appear to influence *P. marksi* occurrence, though the influence seems to be weak at best. It is possible that mating season is also responsible for increased *P. marksi* surface activity and plays a larger factor than abiotic factors mentioned above. Further studies are needed to evaluate the role mating seasons plays in foraging biology and occurrence of *P. marksi.*

Acknowledgments

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