

Estimation of the potential distribution of the Chilean re-cluse spider *Loxosceles laeta* and the spitting spider *Scytodes globula* from preferred temperatures in the laboratory.

CANALS M.¹, CANALS M.J.², TAUCARE-RÍOS A.³

¹ Programa de Salud Ambiental, Instituto de Salud Poblacional, Escuela de Salud Pública Salvador Allende G. and Departamento de Medicina, Facultad de Medicina, Universidad de Chile. Departamento de Zoología, Facultad de Ciencias Naturales y Oceanográficas, Universidad de Concepción.

E-mail: mcanals@uchile.cl

² Instituto de Filosofía y Ciencias de la Complejidad (IFICC).

³ Departamento de Ciencias Ecológicas, Facultad de Ciencias, Universidad de Chile.

Correspondencia: mcanals@uchile.cl

Summary

Loxoscelism is a health problem caused by the bite of spiders of the genus *Loxosceles* (Araneae: Sicariidae). In Chile, all necrotic arachnidism is attributed to the Chilean recluse spider, *L. laeta*, a species that may be preyed upon by the spitting spider *Scytodes globula* Nicolet (Araneae: Scytodidae). The first approximation to the risk of loxoscelism is based on the knowledge of the species distribution but although *L. laeta* and *S. globula* are very common in central Chile and are synanthropic spiders, the distribution of these species is not well known. In this study based on previous estimations of preferred temperatures of *L. laeta* and *S. globula* we estimate the potential distribution of these species and compare with the actual reported presence data. We found that the best predictor was the average temperature. The maps of temperature-based potential distribution of *L. laeta* had a good goodness of fit to presence data. In the case of *S. globula* the goodness of fit was low. The better goodness of fit of the model in *L. laeta* than *S. globula* suggests that in the former species temperature is an important axis of its niche, conditioning the distributions of its populations. However in *S. globula* there was not a good fit of the model suggesting that others niche axis are intervening in its distribution. Other niche axes such as human footprint, precipitation, relative humidity and fluctuations in temperature and rainfall are needed to know the niche and build potential distribution maps of these species to assess zones of potential risk of loxoscelism.

Introduction

Loxoscelism is a health problem caused by the bite of spiders of the genus *Loxosceles* (Araneae: Sicariidae). (Gertsch 1967, Gertsch and Ennik 1983, Reyes et al. 1991, Vetter 2008, Saupe et al. 2011). In Chile, all necrotic arachnidism is attributed to the Chilean recluse spider, *L. laeta*, a species that may be preyed upon by the spitting spider *Scytodes globula* Nicolet (Araneae: Scytodidae) (Canals et al. 2015). The biology of these two species is not well known (Fernandez et al. 2002; Canals et al. 2004, 2008, Canals and Solís 2013, 2014, Taucare-Ríos et al. 2013). *L. laeta* is a solitary spider of domestic habitats, found within households usually in dark corners, cracks, closets, clothing, and bath towels, but can sometimes be found outdoors. Its activity is preferentially nocturnal; high temperatures are a factor that favors its development (Schenone & Letonja 1975, Schenone 1998, 2003, 2004, Schenone et al. 2001). With respect to diet, in Chile it has been reported that this spider feeds on flies, moths, and other small arthropods (Levi & Spielman 1964, Schenone et al. 1970, 1989, 2001, Schenone 1998, 2003, 2004, Parra et al. 2002). From the medical point of view, the epidemiology of loxoscelism incidents coincides with nocturnal activity. Epidemiology also suggests larger spider populations and greater

activity during the summer (Schenone 1998, 2003, 2004, Schenone et al. 2001). A predator of *L. laeta* in Chile is the solitary species, *S. globula*, a member of a group of spiders known as spitting spiders with recognized araneophagic habits (Gilbert & Rayor 1985, Bowden 1991, Canals et al. 2015). During predation these spiders spit an adhesive substance through their chelicerae, immobilizing their prey (Foelix 1996, Araujo et al. 2008). These spiders are active during twilight and night and their thermal preferences and desiccation tolerances are similar to those of *L. laeta* (Alfaro et al. 2013, Canals et al. 2013). *S. globula* is distributed in South America in Chile, Bolivia, Argentina, Brazil, and Uruguay. Like *L. laeta*, this species is common in human dwellings and gardens of houses of central Chile (Fernandez et al. 2002).

Spatial epidemiology can be defined as the study of spatial variation of the exposition probability to an infection (risk) or of the incidence of a disease (Ostfeld et al., 2005, Elliot et al., 2005). Maps have been used in epidemiology with two main objectives: i) retrospective spatial-temporal mapping of epidemic dynamics to understand the factors that govern spatial patterns and the rate of spread of diseases, or to describe the characteristics of traveling waves in epidemics such as measles and dengue hemorrhagic fever, and ii) static risk mapping to characterize the spatial variation in contemporary

risk. The most common procedure is i) to construct distribution maps of the vector, reservoir or disease, ii) use remote-sensing data and geographical information systems to characterize the distribution of abiotic or others conditions, iii) select variables most strongly related to the distribution of the vector, reservoir or disease, iv) project the distribution of the identified variables to other areas or future times to make predictions about risk, and v) guide the imposition of interventions, such as pesticide application or vaccination (Ostfield 2005, Elliot et al., 2005). There are numerous recent applications of maps in the distributions of several infectious diseases such as Hanta virus pulmonary syndrome, leishmaniasis, LaCrosse encephalitis, oncocerciasis, schistosomiasis, tick-borne diseases (see Ostfield et al., 2005 for a review) malaria (Parham & Michael 2010) and dengue (Bath et al., 2013), and also in other countries risk mapping using distribution records, bioclimatic data and geographical information systems has recently been developed (Guhl, 2013). Conceptually the epidemiologic risk maps of vector-borne diseases may be classified into three categories i) ecological maps, based on the distribution of vector and reservoir, ii) eco-epidemiologic maps (such as R_0 -maps), based on geographic variations of the vector-disease interface population parameters, and iii) epidemiological maps, based on geographical variations of the incidence of the disease (incidence-based risk) (Ostfeld et al. 2005; Sakar et al. 2010).

In the case of loxoscelism, an accident that results from the human encounter with *L. laeta*, the first approximation to the risk is based on the knowledge of the distribution of the species (ecological maps). Although *L. laeta* and also *S. globula* are very common in central Chile and are synantropic spiders (Taucare et al., 2013), the distribution of these species is not well known. Although recently several aspect of the thermal niche have been reported (Canals et al. 2013, Alfaro et al. 2013), there were no projections to their potential distribution. By analyzing thermal preferences and tolerances we can estimate the thermal niche, which is one of the niche dimensions. The niche is defined as a multidimensional combination of biotic and abiotic variables required for a species to survive and reproduce. This concept includes the potential (or fundamental) niche, which describes the set of conditions that a population could occupy (i.e. maximum tolerances), and the realized niche that describes the actual set of conditions under

which a population exists and persists over time (i.e. preferred temperatures) (Hutchinson, 1957, 1976; Jaksic & Marone, 2007; Peterson et al. 2011).

In this study based on previous estimations of preferred temperatures of *L. laeta* and *S. globula* we estimate the potential distribution of these species and compare it to the actual reported presence data.

Material and Methods

We consider previous reported data of preferred temperatures of the species *L. laeta* and *S. globula* (Canals et al., 2013). In this study twenty one individuals of *L. laeta* (15 females and 6 males; $mb = 156.46 \pm 69.91$ mg) and 25 individuals of *S. globula* (15 females, 10 males, $mb = 58.8 \pm 27.43$ mg) were exposed to a thermal gradient between 2 °C and 40 °C. This was repeated twice in the morning (09:00, 12:00) and twice in the twilight-night period (18:00, 20:00). Individuals were deposited in the center of the chamber and allowed five minutes of setting. Then the temperature of the spiders was measured at the midpoint of the cephalothorax every five minutes with an infrared thermometer for one hour. For each individual a record of the twelve temperatures chosen by the spiders (1 every 5 min) at 9:00, 12:00, 18:00 and 20:00 was obtained. With these temperature records, frequency histograms of the chosen temperatures were constructed.

For this study the frequency histogram was re-scaled setting the highest frequency to one. Thus, a relationship between probabilities of election and temperature was built ($pp = f(T)$). Also histograms were analyzed for bimodality with Hartigan Dep test. This information was integrated with average and maximum temperatures georeferenced for all the Chilean territory obtained from worldclim.org (global climate data). Using the relationship $pp = f(T)$ local temperatures were translate to election probabilities and mapped in all the Chilean territory using ARCGIS®, resulting in an ecological map of potential distribution of both species.

The final model was compared to occurrence data obtained from the Chilean Museum of Natural History and the Museum of Concepción University. To compare the empirical distribution with the model (a probability map) an ROC analysis of the matrices was performed.

Results

In terms of averages, preferred temperatures were similar for the two species but the probabilities of temperature election of *L. laeta* and *S. globula* was different. Both species had a bi-modal distribution. *L. laeta* showed peaks of choice at 19 °C and 39 °C ($D = 0.452$, $p < 0.001$), and *S. globula* at 12 °C and 22 °C ($D = 0.079$, $p < 0.001$) (Fig. 1).

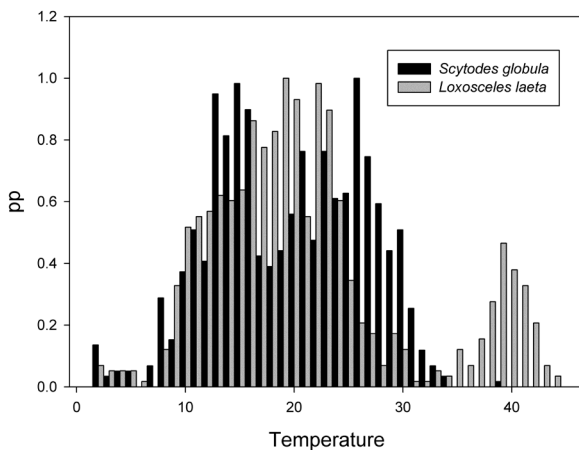


Figure 1. Temperature preference probabilities (pp) based on temperature choice in laboratory of the species *Loxosceles laeta* and *Scytodes globula*.

The best predictor was the average temperature. The maps of temperature-based potential distribution of *L. laeta* (Fig. 2) had a good goodness of fit to presence data (AUC = 0.883) with a break point at $pp = 0.1$ which correspond to a sensitivity of $S = 0.85$ and specificity $Sp = 0.92$ (Fig. 3). However, in urban zones such as Santiago where this species is usually reported the model yielded $pp \approx 0.6$. In the case of *S. globula* the goodness of fit was low (AUC = 0.633) with a break point at $pp = 0.1$, but $S = 0.33$ and $Sp = 0.95$ (Figs. 3 and 4).

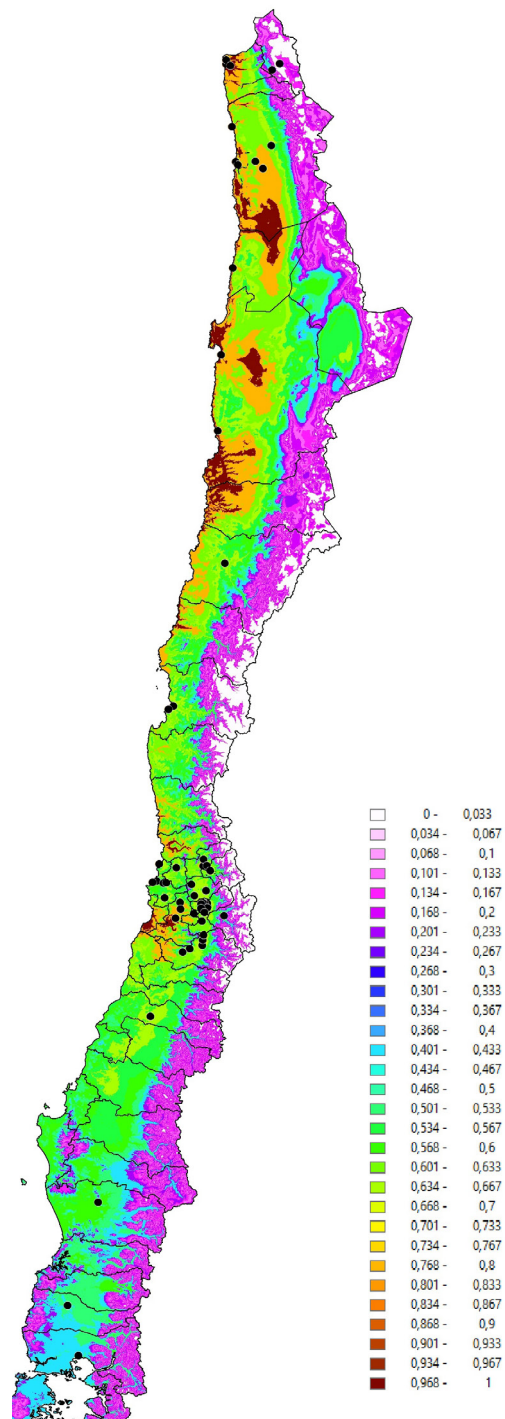


Figure 2. Map of the potential distribution of *Loxosceles laeta* based on preferred temperatures in the laboratory. Black points show the actual presences of this species.

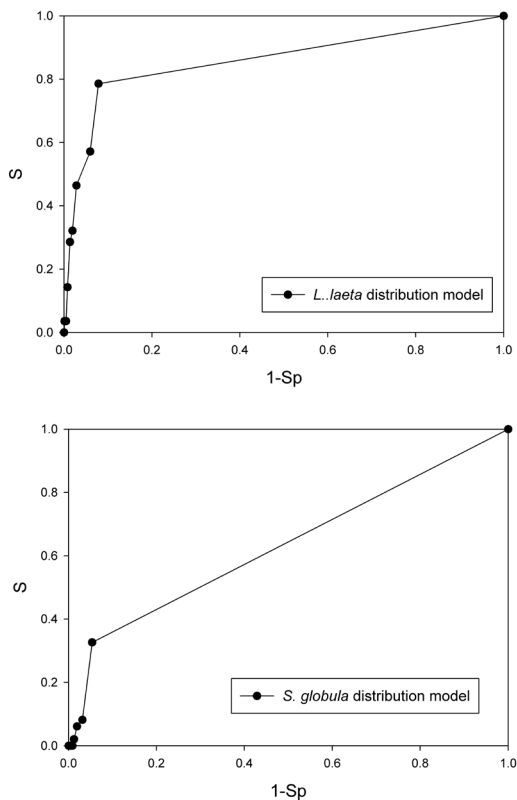


Figure 3. ROC curves for the fitted models of potential distribution for *Loxosceles laeta* and *Scytodes globula*.

Discussion

Mechanistic biophysical ecological methods to assess the niche have been used to quantify the interactions of organisms with their environment; not using the environment *per se* but rather the state of the organism, for example body temperature (Tb). Tb drives an organism's physiological state; thus it is crucial to quantify patterns of body temperature if we are to link controlled laboratory conditions with those in the field. The principles of these models provide a robust approach to determining mechanistically niches of organisms (Kearney, 2006, 2012, Kearney & Porter 2009, Kearney et al. 2010). Body temperature is perhaps the most important ecophysiological variable affecting all aspects of the

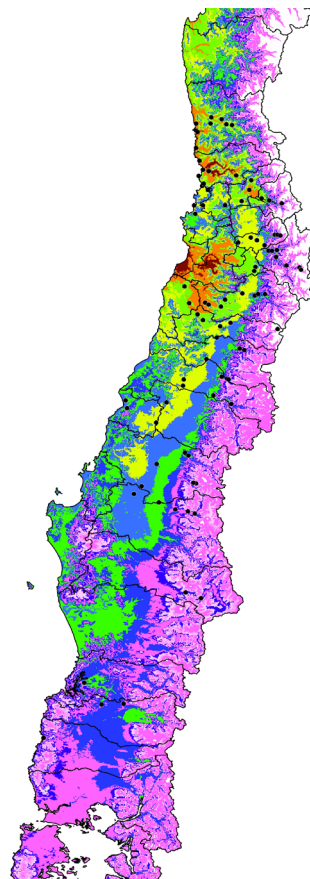


Figure 4. Map of the potential distribution of *Loxosceles laeta* based on preferred temperatures in the laboratory. Black points show the actual presences of this species.

performance of ectotherms, including locomotion, immune function, sensory input, foraging ability, courtship and rates of feeding and growth (Johnson & Bennett 1996, Portner et al., 2006, Angilletta et al. 2002, Angilletta 2009). During exposition to a broad range of temperatures the relationship between performance and temperature is described by a curve in which the thermal optimum is the Tb at which performance is maximum, and the critical thermal limits are the minimum and maximum body temperatures that permit performance (Angilletta et al. 2002). These extreme limits to thermal stress are found beyond the window of aerobic scope for activity, allowing estimation of their acclimation ability and their thermal tolerance ranges (Boher et al. 2010). Thermal thresholds and preferred temperatures are also important in the determination

of arthropod distribution and abundance in response to climate change (Hazell et al. 2010).

Thermal preferences facilitate the description of the ecology of a species and assessment of the suitability of the habitat (Hertz et al. 1993). According to Sevacherian and Lowrie (1972) individual limits and physiological processes determine the conditions in which an organism can survive and adapt successfully to a particular environment (Fisher & Vasconcellos-Neto 2003). *Loxosceles laeta* and *S. globula* have very similar preferred temperatures, which is in agreement with finding the two species in similar micro-environments, particularly in domestic habitats in central Chile (Schenone et al. 1970, 1989, 1975, Alfaro et al. 2013, Canals et al. 2013, Canals et al. 2015). Preferred temperatures for *L. laeta* and *S. globula* are in the range described for other araneomorph species, but in the lower part of the range. Variation in preferred temperature throughout the day has been reported in these species (Alfaro et al. 2013) and in mygalomorph spiders with crepuscular and nocturnal activity (Alfaro et al. 2012). Regarding thermal preferences, both species had standardized thermal niche breadth values slightly greater than 0.6, a value that has been proposed as limit between specialist and generalist species (Alfaro et al. 2013). Thus *L. laeta* and *S. globula* are predominantly eurythermal species, but they have different forms of frequency histograms of preferred temperatures determining different probabilities of election. While in *L. laeta* the pp(t) curve is bimodal with a clear separated peak at 39 °C in *S. globula* the two peak in the distributions are closer to each other. The second peak of *L. laeta* determines high probabilities of temperature election in the upper range of temperatures. This agrees with a more wide range of potential distribution in the model. The better goodness of fit of the model for *L. laeta* than for *S. globula* suggests that in the former species the temperature is an important axis of its niche, conditioning the distributions of its populations. However in *S. globula* there was not a good fit of the model suggesting that others niche axes are intervening in its distribution. Among others niche axes in these spiders the human footprint may be an important factor because *L. laeta* and *S. globula* are a synanthropic spiders and their dispersion is in part a consequence of human dispersion; also human dwellings provide microenvironment of stable micro-environmental and appropriate conditions to

survival and reproduction (Taucare-Ríos et al. 2013). Also other factors not considered in this study such as precipitation, relative humidity, fluctuations of temperature and rainfall condition the distribution of spiders and other arthropods. Furthermore availability of food sources and biotic interactions such as predators, parasites and other infectious agents also condition their distribution.

Acknowledgements We thank Chilean Museum of Natural History and Museum of University of Concepción for facilitate material used for georeferentiation. We thanks Lafayette Eaton for idiomatic corrections and useful comments.

References

- Alfaro C, Figueroa DP, Torres-Contreras H, Veloso C, Venegas F, Canals M. Effect of thermal acclimation on preferred temperatures in two mygalomorph spiders inhabiting contrasting habitats. *Physiol Entomol.* 2012; 38: 20–25.
- Angilletta MJJ, Niewiarowski PH, Navas CA. The evolution of thermal physiology in ectotherms. *J Therm Biol.* 2002; 27: 249–268.
- Angilletta MJJ. *Thermal Adaptation: A Theoretical and Empirical Synthesis.* Oxford: Oxford University Press; 2009.
- Araujo D, Rheims A, Brescovit D, Cella D. 2008. Extreme degree of chromosome number variability in species of the spider genus *Scytodes* (Araneae, Haplogynae, Scytodidae). *J Zool Syst Evol Res.* 1008; 46: 89–95.
- Boher F, Godoy-Herrera R, Bozinovic F. The interplay between thermal tolerance and life-history is associated with the biogeography of *Drosophila* species. *Evol Ecol Res.* 2010; 13: 973–986.
- Bhatt S, Gething PW, Brady OJ, Messina JP, Farlow AW, Moyes CL, et al. The global distribution and burden of dengue. *Nature* 2013; 456:504–507.
- Bowden K. The evolution of sociality in the spitting spider *Scytodes fusca* (Araneae, Scytodidae) evidence from observations of intraspecific interactions. *J Zool* 1991; 223: 161–172.
- Canals M, Solís R, Valderas J, Ehrenfeld M, Cattán PE. Preliminary studies on temperature selection and activity cycle of Chilean vectors of the Chagas disease. *J Med Entomol.* 1997; 34 (1): 11–17.

- Canals M, Casanueva ME, Aguilera M. Cuales son las especies de arañas peligrosas en Chile? Rev Med Chile 2004; 132: 773–776.
- Canals M, Casanueva ME, Aguilera M. Arañas y escorpiones. In: Canals M, Cattán PE, editores. Zoología Médica II. Invertebrados. Santiago: Editorial Universitaria; 2008. p. 145–183.
- Canals M. Biología e historia natural de la araña del rincón *Loxosceles laeta*. Parasitología al día; 2011; 1: 4–5.
- Canals M, Solís R. Is the tiger spider *Scytodes globula* an effective predator of the brown recluse spider *Loxosceles laeta*? Rev Med Chile 2013; 141: 805–807.
- Canals M, Alfaro C, Veloso C, Torres-Contreras H, Solís R. Tolerancia a la desecación y sobreposición del nicho térmico entre la araña del rincón *Loxosceles laeta* y un posible control biológico, la araña tigre *Scytodes globula*. Parasitología Ibero-Latinoamericana 2013; 72 (1): 60–74
- Canals M, Arriagada N, Solís R. Interactions Between the Chilean Recluse Spider (Araneae: Sicariidae) and an Araneophagic Spitting Spider (Araneae: Scytodidae). J Med Entomol. 2015; 1–8; DOI: 10.1093/jme/tju021.
- Elliot P, Wakefield J, Best N, Briggs D. Spatial epidemiology. Methods and applications. Oxford: Oxford University Press; 2005.
- Fernandez D, Ruz L, Toro H. Aspectos de la biología de *Scytodes globula* Nicolet, 1949 (Araneae: Scytodidae), un activo depredador de Chile Central. Acta Entomol Chil. 2002; 26: 17–25.
- Guhl F. 2013. Epidemiología molecular de *Trypanosoma cruzi*. Rev Esp Salud Pública 2013; 1–8.
- Fisher ML, Vasconcellos-Neto J. Determination of the maximum and minimal lethal temperatures (LT50) for *Loxosceles intermedia* Mello-Leitão 1934 and *L. laeta* Nicolet 1849 (Araneae, Sicariidae). J Therm Biol. 2013; 28: 563–570.
- Foelix RE. Biology of Spiders. Oxford: Oxford University Press; 1996.
- Gertsch WJ. The spider genus *Loxosceles* in South America (Araneae, Scytodidae) Bull Am Mus Nat Hist. 1967; 136: 117–174.
- Gertsch WJ, Ennik F. The spider genus *Loxosceles* in North America, Central America and the West Indies (Araneae, Loxoscelidae). Bull Am Mus Nat Hist. 1983; 175: 264–360.
- Gilbert C, Rayor LS. Predatory behavior of spitting spiders (Araneae, Scytodidae) and the evolution of prey wrapping. J. Arachnol. 1985; 13: 231–241.
- Hazell SP, Groutides C, Neve BP, Blackburn TM, Bale JS. A comparison of low temperature tolerance traits between closely related aphids from the tropics, temperate zone, and arctic. J. Insect. Physiol. 2010; 56: 115–122.
- Hertz P, Huey R, Stevenson R. Evaluating temperature regulation by field active ectotherms: the fallacy of the inappropriate questions. Am. Nat. 1993; 142: 796–818.
- Hutchinson VH. Concluding remarks. Cold Spring Harbor Symp. Quant. Biol. 1957; 22: 415–427.
- Hutchinson VH. Factors influencing thermal tolerance of individual organisms. In: Esch GW, McFarlane RW, editors. Thermal Ecology. Springfield: II US National Technical Information Service; 1976. p. 10–26.
- Jaksic F, Marone L. Ecología de comunidades. Santiago: Ediciones Universidad Católica de Chile; 2007.
- Johnson IA, Bennett AF. Animals and temperature. Cambridge: Society for Experimental Biology Seminar Series, Cambridge University Press; 1996.
- Kearney M. Habitat, environment and niche: what are we modeling? Oikos 2006; 115: 186–191.
- Kearney M. Metabolic theory, life history and the distribution of a terrestrial ectotherm. Funct Ecol. 2012; 26: 186–191.
- Kearney M, Porter WP. Mechanistic niche modeling: combining physiological and spatial data to predict species' range. Ecol Lett. 2009; 12: 334–350.
- Kearney M, Simpson SJ, Raubenheimer D, Helmuth B. Modelling the ecological niche from functional traits. Phil Trans R Soc B. 2010; 365: 3469–3483.
- Levi HW, Spielman A. The biology and control of the South American brown spider *Loxosceles laeta* (Nicolet) in a North American focus. Am J Trop Med Hyg. 1964; 13: 132–136.
- Ostfeld RS, Glass GE, Keesing F. 2005. Spatial epidemiology: an emerging (or re-emerging) discipline. TREE. 2005; 20(6): 328–336.
- Parham PE, Michael E. Modeling the Effects of Weather and Climate Change on Malaria Trans Env Health Persp. 2010; 118(5): 620–626.
- Parra D, Torres M, Morillas J, Espinoza P. *Loxosceles laeta*,

identificación y una mirada bajo microscopía de barrido. Parasitol Latinoam. 2002; 57: 75–78.

Peterson AT, Soberon J, Pearson RG, Anderson RP, Martinez-Meyer E, Nakamura M, et al. Ecological niches and geographic distributions. Princeton & Oxford: Princeton University Press; 2011.

Portner HO, Bennett AF, Bozinovic F, Clarke A, Lardies MA, Lenski RE, et al. Trade-offs in thermal adaptation: in need of a molecular to ecological integration. Physiol Biochem Zool. 2006; 79: 295–313.

Reyes H, Noemi I, Gottlieb B. Arácnidos y otros artrópodos ponzoñosos, in Atías A, editor. Parasitología clínica. Santiago: Mediterraneo; 1991. p. 553–565.

Sarkar S, Strutz SE, Frank DM, Rivaldi CL, Sissel B, et al. Chagas disease risk in Texas. PLoS Negl Trop Dis 2010; 4(10): e836. doi:10.1371/journal.pntd.0000836

Saupe EE, Papes M, Selden PA, Vetter RS. Tracking a medically important spider: climate change, ecological niche modeling, and the brown recluse (*Loxosceles reclusa*). PLoS ONE 2011; 6(3): e17731. doi:10.1371/journal.pone.0017731

Schenone H. Cuadros tóxicos producidos por mordedura de araña en Chile: latrosectismo y loxoscelismo. Rev. Med. Chile 2003; 131: 437–444.

Schenone H. A propósito del loxoscelismo en Chile. Rev. Med. Chile 2004; 132: 121–122.

Schenone H. Loxoscelismo cutáneo de predominio edematoso. Bol Chil Parasitol. 1998; 53: 78–83.

Schenone H, Rubio S, Saavedra S, Rojas A. Loxoscelismo en pediatría: región metropolitana. Chile. Ver. Chil. Pediatr. 2001; 72 (2): 100–109.

Schenone H, Rojas A, Reyes H, Villarroel F, Suarez G. Prevalence of *Loxosceles laeta* in houses in central Chile. Am J Trop Med Hyg. 1970; 19: 564–567.

Schenone H, Saavedra T, Rojas A, Villarroel F. Loxoscelismo en Chile. Estudios epidemiológicos, clínicos y experimentales. Rev. Inst. Med. Trop. Sao Paulo 1989; 31: 403–415.

Sevacherian V, Lowrie D. Preferred temperature of two species of lycosid spiders, *Pardosa sierra* and *P. ramulosa*. Ann Entomol Soc Am. 1972; 65: 111–114.

Taucare-Ríos A, Brescovit AD, Canals M. Synanthropic spiders (Arachnida: Araneae) from Chile, the most common spiders in anthropogenic habitats. Rev Iber Aracnol. 2013;

23: 49–56.

Vetter R. Spiders of the genus *Loxosceles* (Araneae, Sicariidae), a review of biological, medical and psychological aspects regarding envenomations. J Arachnol. 2008; 36: 150–163.