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Size structure and sex ratio of *Ammotrechella manggi* (Solifugae: Ammotrechidae) in the mangrove forest of the south of Morrosquillo Gulf, Colombian Caribbean

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Abstract: Studies on size structure and reproduction periods were conducted in populations of *Ammotrechella manggi* Acosta-Berrocal, Bedoya-Roqueme, Salleg-Perez & Quirós-Rodríguez, 2017 in fragments of mangrove forest of the municipality of San Antero, Córdoba, Colombian Caribbean. A total of 81 individuals were collected, of which 37 were nymphs, 17 subadults, and 27 adults, and of these 19 females and 8 males were categorised. There was sexual dimorphism in the size of the pedipalps and propeltidium for *A. manggi* but without any significant differences. Apparently it has a univoltine cycle and gregarious behaviour. The reproduction periods suggest that its selective strategy linked to reproduction is adjusted to the climatic seasons of the mangrove forests and the exclusivity of *A. manggi* in the microhabitats where it develops.
Key words: Solifugae, Ammotrechidae, ecology, microhabitat, sexual dimorphism, Colombia, San Antero.

Estructura de tallas y ratios sexuales de *Ammotrechella manggi* (Solifugae: Ammotrechidae) en fragmentos de manglar del sur del golfo de Morrosquillo, Caribe colombiano
Resumen: Se realizaron estudios sobre estructura de talla y períodos de reproducción en poblaciones de *Ammotrechella manggi* Acosta-Berrocal, Bedoya-Roqueme, Salleg-Pérez & Quirós-Rodríguez, 2017 en fragmentos de bosque de manglar del municipio de San Antero, Córdoba, Caribe colombiano. Se recolectaron un total de 81 individuos, de los cuales 37 eran ninfas, 17 subadultos y 27 adultos, y de ellos se categorizaron 19 hembras y 8 machos. Se evidenció dimorfismo sexual en el tamaño de los pedipalpos y propeltidio, pero sin diferencias significativas. Aparentemente tiene un ciclo univoltino y comportamiento gregario. Los períodos de reproducción sugieren que su estrategia selectiva ligada a la reproducción se ajusta a las temporadas climáticas de los manglares y la exclusividad de *A. manggi* en los microhábitats donde se desarrolla.
Palabras clave: Solifugae, Ammotrechidae, ecología, microhábitat, dimorfismo sexual, Colombia, San Antero.

Introduction

The solpugids are arachnids characterized by strong chelicerae, long pedipalps, and the absence of venom, being widely distributed in desert and semi-desert areas, and diverse in the tropics and subtropics (Punzo, 1991; Belozerov, 2013; Harvey, 2003; González, 2015). In terms of diversity, it is considered a lesser-order group, with 1187 species, 141 genera, and 12 families (Belozerov, 2013; Harvey, 2003; González, 2015). In general, the representatives of the family Ammotrechidae are tolerant to high levels of humidity, adapted to coastal ecosystems, wetlands, and mangroves, being different from other sun-spiders that are present in arid regions, adapted to low rainfall, extreme temperatures, and scarce vegetation typical of xerophilous ecosystems (Punzo, 1991; Belozerov, 2013). However, due to their low abundance, solpugids are difficult to collect and poorly attended by arachnologists, so aspects such as biology, behavior, and ecology remain relatively scarcely studied and focused only on the ecosystems where they are more abundant (Hutton, 1843; Lawrence, 1942, 1955; Cloudsley-Thompson, 1977; Punzo, 1991; Muma, 1951; McCormick & Polis, 1990; Iuri *et al*., 2014; Muma, 1971; Posada, 2004; Valdivia *et al*., 2008; Catenazzi *et al*., 2009; Valdivia *et al*., 2011; García *et al*., 2014).

The sexual proportion is defined as the ratio between the number of males and females in a population. It is accepted that in many assemblages of invertebrates there is an equal number of individuals in both sexes of most species, which tends to be 1:1 (Fisher, 1930); however, some species have been observed to deviate from this ratio, to maximize evolutionary success and long-term prospects for a given population (Hjernquist *et al*., 2009; Tabadkani *et al*., 2012; Wedekind, 2012). In arachnids, some representatives, such as spiders, exhibit a sex ratio biased towards females, while other species have a sex ratio of 1:1; most species present annual life cycles, but this proportion is well extended among arachnids (Gabbutt, 1970; Polis, 1990; Foelix, 2011; Belozerov, 2013).

However, marked variations have been reported among spiders, *Anelosimus eximius* Keyserling, 1884 (Theridiidae) has a sex ratio that favors females of 5:1; while *Larinioides cornutus* (Clerk, 1757) (Araneidae) and species of the family Pholcidae exhibit a 1:1 ratio; while *Metagonia taruma* Huber, 2000 presents differences, attributed to stochastic variations (Vollrath, 1986; Ysnel, 1991; Machado *et al*., 2007; Carvalho *et al*., 2010; Foelix 2011). Some species of scorpions have a sex ratio that favors females of 1:3 and Opiliones *Megabunus diadema* (Fabricius, 1799) (Phalangiidae) is considered parthenogenic, however, species of *Prionostemma* (Opiliones) have a 1:1 (Merino-Sáinz *et al*., 2013; Grether *et al*., 2014; Kassiri *et al*., 2015).

The proportion of sexes present in nature tends to always be 1:1 and indicates equally important roles between males and females since the selection could minimize the less productive sex, hence the sex ratio of 1:1 suggests, that the cost of successfully raising nymphs, is pretty much the same regardless of the sex (Fisher, 1930; Smith, 1999; Wade *et al*., 2003; Tabadkani *et al*., 2012; Wedekind, 2012). Therefore, it was considered essential to know and establish the sexual dimorphism and sexual proportion of these arachnids in littoral environments. In this sense, the sexual ratio of *Ammotrechella manggi* Acosta-Berrocal, Bedoya-Roqueme, Salleg-Perez & Quirós-Rodríguez, 2017, sexual dimorphism and reproduction periods in the mangrove forest fragments of the department of Córdoba, Colombian Caribbean, was the object of study in the present study.

Materials and methods

The study was conducted in four fragments of mangrove forests from the southern part of the Gulf of Morrosquillo, located at 9° 24 '34.29" N and 45' 20.95" W, in the municipality of San Antero, department of Cordoba, Colombian Caribbean, which are separated from each other by an average of 2.3 km, being the fragment of mangrove forest of Punta Nisperal the most distant, located approximately 5.72 km from the fragment of Playa Blanca (Table I). In general, the average annual precipitation is 1337.4 mm, and the average annual temperature varies between 28-32.9 °C (Cortes & Rangel, 2011); the precipitation regime is adjusted to a unimodal-biseasonal pattern, presenting a dry season (December to March) and a rainy season (April to November); however, in July there is a decrease in rainfall (CVS & INVEMAR, 2010). The solpugids were collected between November 2015 and July 2016, covering the different climatic seasons (one dry, one rainy, and transitional season). The selection of each of the sites was made, considering the state of conservation, the forest structure, microhabitats, and the presence of specimens. Geographically positioned using a GPS Garmin mark (± 15 m).

Table I. Geographical coordinates of the evaluated mangrove forest fragments in the municipality of San Antero.

		Location	
Nº	Locality	Latitude (N)	Longitude (W)
1	Punta Bolívar	9°25'14.5"	75°43'52.0"
2	Punta Bello	9°25'13.0"	75°44'44.1"
3	Playa Blanca	9°24'50.5"	75°45'10.8"
4	Punta Nisperal	9°23'38.2"	75°47'30.5"

The methodologies proposed by Muma (1974, 1979, 1980); Xavier & Rocha (2001); Rocha & Carvalho (2006), and Valdivia *et al*. (2011) were adapted and applied. The specimens were sampled using a random preferential model, directly from their refuges within the bark, using manual collection (07:00-16:00 hrs.), from ground level to 3 m height, for an effective time of 60 min/collector, covering an approximate area of 1 122.01 m^2 for the four sectors under study. The specimens were stored in plastic jars, preserved in 70 % ethanol, and labeled with information that contained the sample code, sector, date, and time. Taxonomic identification follows Muma (1951), Roewer (1934), and Acosta-Berrocal *et al*. (2017). After the study, the collected specimens were deposited in the Zoology Laboratory of the University of Córdoba (CZUC), Montería, Colombia.

To establish the structure and evaluate sexual dimorphism, initially we measured the length and width of the propeltidium and the length of the pedipalps according with Muma (1951) and Bird *et al*. (2015), using a micrometer attached to the stereomicroscope (Carl Zeiss, Axiostar, Germany) and using the software AxioVision Rel.4.9.1.SE64. Subsequently, males were identified by the presence of flagellum in the ectal view of the chelicerae and the ctenidia in the second and third opisthosomal sternites; females were identified by the development of the genital opening, the flagellum and ctenidia absent (Punzo, 1998; Bird *et al*., 2015).

To classify each of the stages, as adult individuals were considered those that presented the developed sexual characteristics (flagellum in males, sclerotized genital opening in females), and nymphs at all juvenile stages (Muma, 1971; Punzo, 1998; Rocha, 2002; Hrušková-Martišová et al., 2010; Belozerov, 2013). Finally, during the study, only two females live pregnant, and one with egg were collected, subsequently studied, and observed in the laboratory following the recommendations made by (Muma, 1966a, b, c, d; Punzo, 1998; Belozerov, 2013). The females were kept in terrariums, at room temperature and relative humidity, while the eggs were kept under controlled conditions of temperature (26-28ºC) and humidity (70%), to prevent damaging the samples.

To differentiate the development stages of the specimens, initially a data matrix was organized with the morphological measurements of propeltidium and pedipalp, and the average, standard deviation, ranges, and coefficients of variation were calculated. The T-Student and the Mann-Whitney U tests were used to compare the body measurements of the specimens and evaluate sexual dimorphism (Gotelli & Ellison, 2004). The sexual ratio was calculated with the mathematical formula (F / M) using the length-frequency distributions for both females and males (Smith, 1999). A Chi-square (X^2) test with their respective contingency tables was performed to establish if there were differences between the number of males and females. All analyzes were performed using the R software v. 4.1.0 (RCore Team, 2021).

Results and discussion

A total of 81 individuals were collected, of which 37 were nymphs, 17 subadults, and 27 (19 females, 8 males) were adults. The average length of the pedipalps for females was 5.6 ± 0.6 mm, the length of the propeltidium 1.5 ± 0.3 mm, and the width 1.9 ± 0.3 mm; in contrast, the average length of the male pedipalp was 6.5 ± 0.5 mm, the length of the propeltidium 1.5 ± 0.1 mm and the width of the propeltidium 1.4 ± 0.2 mm, which was smaller in comparison with females (Table II). Significant differences (W = 147; P <0.0001) were found in pedipalp length (Figure 1A), and the propeltidium width (Fig. 1B), showing sexual dimorphism among individuals (W = 13.5; $\alpha = 0.05$; P = 0.009). The length of the propeltidium does not present significant differences (W = 61; P <0.44), therefore, it is not considered sexual dimorphism. The males were significantly (P <0.001) larger than the females in pedipalp length (Fig. 1A). Similarly, the females were larger (P<0.0029) than the males in the width of the propeltidium (Fig. 1B). The regression analysis between total body length and pedipalp length by sex was significant (p <0.0029), 82% of the variation was explained for males and 87% for females (Fig. 2A). The relationship with the width of the propeltidium was significant (p <0.01), 87% of the variation was explained by females and 81% by males (Fig. 2). Significant differences (ANCOVA) were observed between the relationships of the size structure, the length of the pedipalp, and the width of the propeltidium for females and males (F = 661.2: P<0.0026), which supports sexual dimorphism in this species of solpugid.

Table II. Size structure (mm) of the developmental stages of *A. manggi* in mangrove forest fragments from Córdoba, in the Colombian Caribbean.

Pedipalp Length					
	Abundance	Average	Standard deviation	Maximum	Minimum
Subadults	17	5.10	0.11	5.21	4.9
Females	19	5.61	0.61	6.11	4.1
Males	8	6.51	0.51	7.70	6.0
Propeltidium Length					
	Abundance	Average	Standard deviation	Maximum	Minimum
Subadults	17	0.91	-	1.0	0.9
Females	19	1.50	0.3	1.9	1.2
Males	8	1.50	0.1	1.8	1.4
Propeltidium Width					
	Abundance	Average	Standard deviation	Maximum	Minimum
Subadults	17	1.0	0.1	1.1	0.9
Females	19	1.9	0.3	1.5	1.5
Males	8	1.4	0.2	1.8	1.3

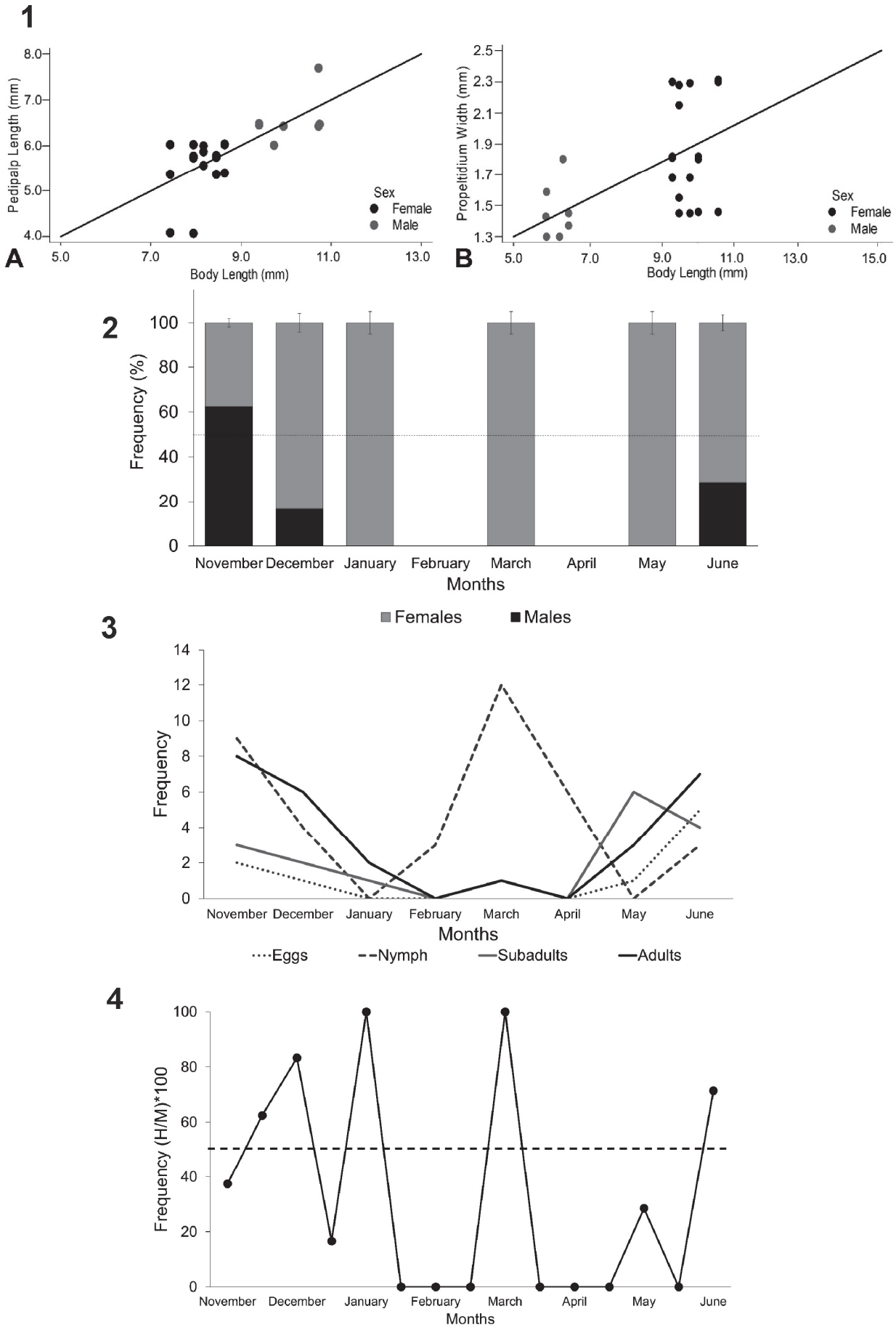


Fig. 1. Relationship body length (mm): A, Pedipalp, length per sex. B, Propeltidium width per sex of *Ammotrechella manggi* in mangrove forest fragments from Córdoba, in the Colombian Caribbea. **Fig. 2.** Frequency sex of *Ammotrechella manggi* in mangrove forest fragments from Córdoba, in the Colombian Caribbea. **Fig. 3.** Variation in the number of adults (females and males) and nymphs of *Ammotrechella manggi* in mangrove forest fragments from Córdoba, in the Colombian Caribbea. **Fig. 4.** General trend, sex ratio (H/M) for *Ammotrechella manggi* in mangrove forest fragments from Córdoba, in the Colombian Caribbea.

The difference between the frequency of males and females did not present significant differences (X^2 = 11.070; gl = 5; P> 0.209), which does not show that the relationship is uniform, therefore, it is risky to infer a sex ratio of 1: 1 in populations of *A. manggi* in the evaluated mangrove forest fragments, it is necessary to conduct more studies focused on this aspect. However, there were fluctuations in the number of individuals during the studied months, the males were collected in November, December, and July, with November being the month where the highest abundance values were recorded (Fig. 3); the females were collected in all the studied months, except March and May, being most abundant in December and July, months where the nymph record increased until April (Fig. 4). The frequency in females (0.020-0.180 ± 0.10) increased in December, then in March and later in May (Fig. 4), while it increased in males (0.035-0.070 ± 0.052) in January, significantly in March and considerably in June, coinciding with the females, which, following the trend and the frequency of nymphs, this suggests that *A. manggi* shows univoltine behavior in fragments of mangrove forests of San Antero.

The number of nymphs, subadults, and adults recorded indicates that mangrove fragments offer the necessary conditions, both for refuge and food, throughout their life cycle. According to Punzo (1998), the life cycle of solpugids consists of egg, post-embryo, nymphs (8-10 instars), and adults, all post-embryonic development (from egg to adult stage) encompassed an average of 226 days for males and 240 days for females, similar to the duration of the life cycle of *A. manggi* (242 days) (Punzo, 1998; Lawrence, 1955; Muma, 1966; Hingston, 1925; Lawrence, 1946; Cloudsley-Thompson, 1961; Junqua, 1966); the growth rates of this species were measured in terms of changes in the length and width of the propeltidium and the length of the pedipalps, successfully differentiating nymphs, subadults, and adults; however, within these categories it was impossible to discern how many instars the nymphs presented during the sampling months, considering that the climatic periods and the consequent change in the food supply influence the size of the individuals, so that the measurements did not present significant differences, varying considerably between specimens (Koch, 1842; Hansen, 1901; Kraepelin, 1901; Hirst, 1912; Roewer, 1934; Fitcher, 1940; Frade, 1940; Lawrence, 1942; Brookhard & Muma, 1981; 1987).

Sexual dimorphism was characterized in terms of the presence of flagellum in males and sclerotization of the genital plate in females, however, differences were found in other body structures, being the males characterized by a greater length in pedipalps and females by having a wider propeltidium, although in most species of the genus *Ammotrechella*, the propeltidium of the males is wider than long, they have smaller structures than the females such as the chelicerae, eyes, legs, etc. (Koch, 1842; Roewer, 1934; Muma, 1951. The fluctuation appreciated between the number of males and females concerning their presence in the months of sampling, some studies suggest that the longevity of males may be less than that of females because they die shortly after mating and the greater longevity of females may be associated with the additional time required for egg development and oviposition (Muma, 1963; 1974; 1979; Punzo, 1998).

Considering the periods of the presence of males and females, and the peak of the abundance of nymphs in April, it could be inferred that *A. manggi* is univoltine, like the majority of solpugids (Muma, 1974; Punzo, 1998), developing a single generation per year. This is largely determined by the rapid development of nymphs and the short life of adults of both sexes. However, there are also some species with bivoltine development (two annual generations), such as *Metasolpuga picta* Wharton, 1987, as well as those with perennial development with two years or more, such as *Gluvia dorsalis* Latreille, 1817, adjusting their cycle of life and reproduction period at the beginning of the rainy season (Belozerov, 2013), using the bark of trees as nesting sites and refuge for nymphs. Some authors suggest that adults live a relatively short time, as are the cases of *Othoes saharae* Panouse, 1960, which lives for about a week; *Eremobates durangonus* Roewer, 1934, for approximately one month; and *E. marathoni* Muma, 1951 females from 1 to 3 months (Muma, 1966; Junqua, 1966; Punzo, 1998).

Ammotrechella manggi exhibits an aggregate distribution in all its stages of development, although they are not close to each other, they share the microhabitat and its resources making use of cavities, cracks, crevices or burrows; similarly, studies on arachnids have shown that most of the species, although they share the microhabitat during the early life stages, as is the case of *Eremobates palpisetulosus* Fichter, 1941, which presents aggregated distribution in first instar nymphs maintaining a narrow proximity to each other and after ecdysis there is cannibalism and the consequent dispersal or courtship activities.

Likewise, certain environmental parameters can allow grouping in different degrees such as the distribution of habitat resources, types of vegetation and food availability, understanding that if the density of prey is unusually high and the characteristics of the microhabitat are favorable, they can form fortuitous aggregations (Colebourne, 1974; Burgess & Uetz, 1982; Buskirk, 1981; Leborgne & Pasquet, 1987). The age structure recorded, sex ratio and the univoltine reproduction cycles suggest a true adaptation of these arachnids to the changes produced by the dominant unimodal-b-seasonal cycle in the area.

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