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Caves as a Winter Refuge by a Neotropical Harvestman (Arachnida, Opiliones)

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Organisms may respond to regular and predictable environmental changes by migrating to regions where resources are available and/or the conditions are more favorable (Dingle and Drake 2007). Although migration is usually associated with long-distance displacements, like those of some birds and butterflies, less vagile animals may also migrate through considerably shorter distances (Kraus and Morse 2005). In fact, the term migration covers a wide range of population displacements (Dingle and Drake 2007), and includes seasonal movements into shelters where the environmental conditions are expected to be less affected by the external environmental changes. Caves are a good example of seasonal shelter, generally with a permanently high humidity and stable temperature even during the winter (Culver and Pipan 2009). Several species do indeed use caves as winter refuges, including insects (e.g. Tercafs 2000), arachnids (Holmberg et al. 1984; Novak et al. 2004), and vertebrates like bats (Lewis 1995), baboons (Barrett et al. 2004), snakes (Sexton and Hunt 1980), and frogs (Resetarits 1986). We highlight, however, that all these examples are from animals living in temperate regions. As far as we know, there is so far no record of the use of caves as winter refuges by animals that are not from temperate regions. This is probably related to the less stressful climatic conditions of the cold period when compared to the harsh winter of temperate regions.

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The Order Opiliones (Arachnida) is rich in examples of species inhabiting caves (see review in Curtis and Machado 2007). These include troglobitic species (species whose entire life cycle is spent inside a cave and whose individuals frequently present morphological adaptations to the cavernicolous environment, e.g. the genus *Texella*), troglophilic species (species that present populations that complete their life cycle inside caves and others who do not, e.g. *Daguerreia inermis*) and trogloxene species (organisms that use the cave only during part of their life, like some *Gyas* that hibernate in caves in Eastern Europe and the Brazilian *Serracutisoma spelaeum*, a strict trogloxene that leaves the cave at night to forage in the forest) (Gnaspini et al. 2003; Curtis and Machado 2007). However, there are so far no examples of harvestmen species using the cave only as winter shelter in tropical areas.

In this study, we describe the seasonal migration of a Neotropical species of harvestman, with use of caves as winter refuge in a sub-tropical area. The harvestman *Serracutisoma proximum* (Laniatores, Gonyleptidae, Goniosomatinae) is endemic to the South and Southeast of São Paulo state, Southeastern Brazil. This species is particularly common in the Ribeira Valley, an Atlantic forest reservation in the Southeast of São Paulo (Gnaspini 1996; Machado 2002; Buzatto et al. 2007; DaSilva and Gnaspini 2010). This is an area covered with dense humid subtropical forest with perennial foliage, with a subtropical humid climate and two distinct seasons: a wet and warm period from October to March (summer) and a dryer and colder period from April to September (winter), when frosts may occasionally occur (e.g. Gnaspini 1996). During the warm and wet season, males and females of *S. proximum* can be found on the vegetation, close to rivers or near cave entrances (when available). Females of *S. proximum* care for their eggs until hatching (Ramires and Giaretta 1994), and this species present a marked reproductive seasonality (Buzatto et al. 2007). Although other Goniosomatinae may lay their eggs on rocky surfaces either inside caves (Gnaspini 1995; Machado and Oliveira 1998; Willemart and Gnaspini 2004a), or outside caves (Machado 2002), *S. proximum* females lay eggs mostly on the underside of leaves hanging above rivers (Buzatto et al. 2007; but see Ramires and Giaretta 1994; and Gnaspini 1996). Buzatto et al. (2007) found that reproduction occurs only during the wet and warm season, when males establish harems and fight for the defense of reproductively suitable territories and females (Buzatto and Machado 2008). During the cold and dry season, however, they noticed that only a few individuals were found active on the vegetation, and only at night, although both males and females survive for the next year and may reproduce in more than one reproductive season (Buzatto et al. 2007). Santos (2003) found individuals of the same population of *S. proximum* studied by Buzatto and colleagues composing aggregations in rock crevices during the cold and dry season (winter), indicating that this species may seek shelter against unfavorable conditions.

We found a population of *S. proximum* living, during the cold and dry season, in the Moquem Cave (24°18′50.4″S 48°27′18.8″W, at an altitude of approximately 750 m), Intervales State Park, Ribeira Valley. Given that *S. proximum* is rarely found on the vegetation during this season (see above), we followed this population through 17 months, in order to describe how this population relates to the cavernicolous habitat. More specifically, we aimed to determine if this population used the cave only as a winter shelter, leaving it during the summer, or if it was established in the cave year round.

We collected our data along 15 field trips with an around 35 days time interval, between August 2004 and December 2005. In each monthly visit to the cave, we counted all the individuals of *S. proximum* found in the cave and identified their sex and developmental stage (namely, adult or juvenile). The Moquem cave is approximately 90 m in length and is crossed by a stream that originates and follows in the forest. However, we concentrated our study on an area of approximately 40 m of length, comprising the two main chambers of the cave and the passage between them, and representing the areas whit a higher density of *S. proximum* individuals. The other 50 m of the cave consist in narrow and irregularly shaped passages, where the sampling of all the individuals would be less precise due to the high possibility of individuals being hidden in crevices or other places inaccessible to our eyes.

To describe the seasonal climatic variation along our study we used meteorological data provided by the Intervales State Park. These data were taken daily, three times a day (0800 h, 1,400 h and 2,000 h), in a meteorological station about 7 km from the study cave. According to these data, the temperature during the wet and warm season (summer) varied between 8°C and 33°C (mean ± s.d.=18.66±3.92°C), and the relative humidity varied from 39% to 100% (mean ± s.d.=86.02±12.99%). During the dry and cold season (winter) the temperature varied between 1°C and 31°C (mean ± s.d.=14.93±4.9°C) and the relative humidity varied from 24% to 100% (mean ± s.d.=83.11±17.89%). We also took measures of the temperature and relative humidity in six different points inside the cave. The temperature inside the cave during the wet and warm season varied between 16.8 and 19.9°C (mean ± s.d.=17.66±1.25°C), while the relative humidity varied between 94.8 and 100% (mean ± s.d.=95.74±2.59%). During the dry and cold season the temperature inside the cave varied between 16.3 and 18.6°C (mean ± s.d.=17.14± 0.84°C), and the relative humidity varied between 93 and 97.8% (mean ± s.d.=95.3± 2.35%). For comparative reasons, other climatic data from the area, either inside or outside caves, can be seen in Gnaspini (1996).

Summing all visits to the cave, we counted 793 individuals of *S. proximum* along the 17 months of study. Among these, we found 709 individuals during the dry and cold months corresponding to winter (summing data from 2004 and 2005) (monthly mean=118.2; range=45–205), versus 84 in the wet and warm months corresponding to summer (monthly mean=9.3; range=0–36) (Fig. 1). However, since the individuals were not individually marked, we may have counted the same individual in more than 1 month. This pattern differs strongly from others species of cavernicolous Gonisomatinae harvestmen, where the number of individuals remains generally stable, with an increase during the wet and warm season mainly due to an input of juveniles (Gnaspini 1996; Machado and Oliveira 1998; Willemart and Gnaspini 2004b). Among the 793 individuals of *S. proximum* that we found in the cave, 493 were aggregated with two to 80 other individuals (mean = 14.4 individuals per aggregation), either conspecifics (adults and juveniles older than the 4th instar) or, less often, with individuals of *Serracutisoma spelaeum*, a syntopic cavernicolous harvestman also found in the area (e.g. Gnaspini 1996). These aggregations contained both males and females of *S. proximum*, suggesting that the male's aggressiveness associated with the defense of females and territories (Buzatto and Machado 2008) is relaxed during the non- reproductive season. We did not find any aggregations during the wet and warm season. We found nine females of *S. proximum* guarding eggs inside the cave, seven during the wet and warm season and

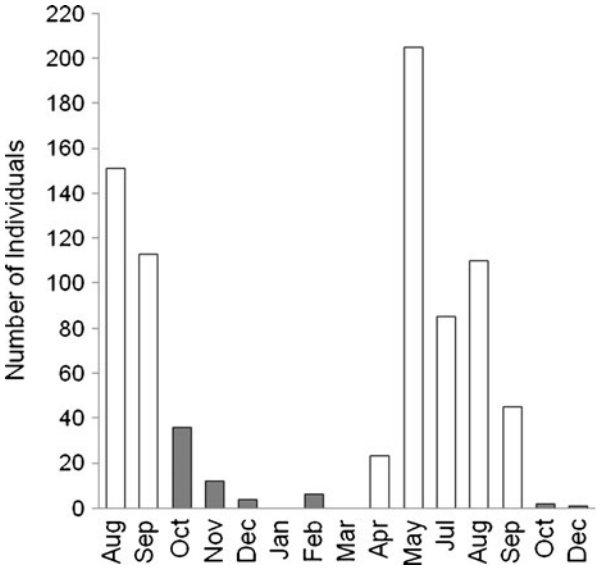

Fig. 1 Seasonal variation in the number of individuals of *Serracutisoma proximum* found in the cave per month. The cold and dry season months are in white and the wet and warm season months are in grey

two in late September 2005, which may be considered the end of the dry and cold season. This very low number of guarding females indicates that *S. proximum* rarely uses the cave for reproduction. Although we did not count the individuals located outside of our 40 m sample area, our result is sufficiently consistent to allow us to discard the possibility that the smaller number of individuals found during the warm and wet season may be explained by the fact the the missing animals are sheltered in inaccessible parts of the cave. Indeed, we seldom found *S. proximum* in the deeper areas of the cave, and our results clearly indicate that the cave is seldom used as a habitat for reproduction.

Our results indicate that *S. proximum* uses the cave only as a winter shelter, behavior that may be categorized as an annual round-way migration according to the classification of Dingle and Drake (2007). This sort of migration is unusual among arthropods, whose typically short life cycle usually allows only one migration, generally from a roosting site to a breeding area, or sometimes several migrations along a single reproductive season (Dingle and Drake 2007). Goniosomatinae harvestmen, however, live more than 3 years (Gnaspini 1995; Buzatto et al. 2007), being therefore able to migrate annually from the winter shelter to the breeding area and vice versa. Considering that the climatic variations in Southeastern Brazil are not as drastic as those of temperate zones, it is probable that most species, including other populations of *S. proximum*, overpass the cold and dry season in their regular habitat, or may use strategies for winter protection other than the migration described here. Indeed, since there is no cave in the vicinity of the study site used by Buzatto et al. (2007) and Buzatto and Machado (2008), migration to caves may not be the only strategy used by *S. proximum* to survive the cold and dry months. Individuals from regions lacking caves may overpass the cold and dry season sheltering inside rock crevices, as witnessed by Santos (2003). Indeed, although the study site used by Buzatto et al. (2007) and Buzatto and Machado (2008) does not have any cave on

the vicinity, large irregular piles of rocks or even rock walls are very common, a typical feature of the Atlantic rain forest in the area. The facultative nature of this migratory behavior may explain why migration and use of caves as winter refuges has never been described in tropical areas.

For the population of *S. proximum* studied here, the migration probably constitutes a way to combine protection against the unfavorable conditions of the cold and dry months and the optimal conditions for reproduction during the wet and warm season. Tropical harvestmen are very sensitive to temperature and humidity variations (Santos 2007). It is also known, from laboratory experiments, that individuals of *S. proximum* prefer places with relative humidity higher than 90% (Santos 2003). This is the approximate humidity found year round in the caves of the Ribeira Valley, along with a temperature with low variation (Gnaspini 1996). The cave seems therefore to be better suited to *S. proximum* during the cold and dry season than the forest. During the wet and warm season, however, the humidity on the vegetation flanking the stream that crosses the Moquem cave is probably high enough to allow the individuals to return to reproduce in the forest, since their reproductive behavior is strongly associated with this vegetation (Buzatto et al. 2007).

In conclusion, *S. proximum* uses the cave only as a winter refuge, and returns to the forest to reproduce during the wet and warm season, a behavior that may allow individuals to get protection against the unfavorable conditions of the characteristically dry and cold winter of Southeastern Brazil's Atlantic forest. The high sensitivity of harvestmen to variation in temperature and humidity and the peculiar reproductive behavior of *S. proximum* in particular, together make this likely probably the first example of a tropical animal using caves as winter shelters.

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