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# Scorpion diversity in two different habitats in the Arid Chaco, Argentina

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**Abstract** Scorpions are one of the most important taxa of predators in terms of density, biomass, and diversity in various areas of the world. In this study, we compared population- and community-level data between a mature and a secondary forest in the Chancaní Reserve (Córdoba, Argentina). Scorpions were collected using pitfall traps (54 nights per site), and their nocturnal activity was observed by means of UV light (26 nights per site) over 7 months. Seven species of scorpions (1964 individuals) were observed in the study area (Bothriuridae and Buthidae). *Brachistosternus ferrugineus* composed >74 % of all individuals and was numerically dominant in most months. It was the most common species sampled with UV light method in all months (85.73 % in mature and 81.80 % in secondary forest). *Timogenes elegans* was the most common species sampled with the pitfall traps method in secondary forest (48.58 %). General sex ratio (males:females) for *B. ferrugineus* was 1:1.24 and for *T. elegans* was 1:0.53. The Shannon index was not significantly different between sites. Species richness was similar, and the Jaccard index was  $C_s = 0.86$ , indicating that both sites share 86 % of the species. *Tityus confluens* was the only species not shared between sites. Our results indicate that species composition in regenerating forest resembles that of

primary forest after c. 15 years, but the relative abundances of these species differ.

**Keywords** Scorpiones · Arid Chaco · Mature forest · Secondary forest · Diversity · Habitat

## Introduction

Scorpions are one of the most important taxa of predators in terms of their density, biomass and diversity. Lourenço (1994) suggested that one of the areas exhibiting the highest alpha-diversity for scorpions in the world included southern Colombia, Ecuador, the northeast region of Peru, and the Upper Amazon region of Brazil. However, density and diversity is also high in various semiarid and arid areas of the world. In these areas community-wide scorpion density averages >3,200 specimens/ha and diversity is high in these habitats, with 3–11 species commonly occurring sympatrically (Polis 1990, 1993).

The combination of relatively high diversity and high density results in a community-level standing biomass that is often greater than other arthropod taxa (except perhaps ants and termites) and may be greater than all vertebrate taxa combined (Polis 1990, 1993; Polis and Yamashita 1991). Scorpions are ecologically important in arid habitats and have the potential to strongly affect community dynamics and structure, especially among arthropods (Polis 1990, 1993; Polis and Yamashita 1991). However, the ability to assess this is limited by the lack of basic population- and community-level data for scorpion assemblages (Brown et al. 2002). Indeed, assessing the general ecological importance of scorpions in xeric habitats is difficult for several reasons. First, there is little data on population-level characteristics (such as density or standing biomass)

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of most arid zone species. Much of the available data is derived from studies on a couple of species of a single ecomorphotype: obligate burrowers, such as *Smeringurus mesaensis* (Stahnke, 1957) (Polis and McCormick 1986) and *Paruroctonus utahensis* (Williams, 1968) (Bradley 1986), both belonging to the family Vaejovidae. Second, data on community-level attributes are even less common and come from a limited number of habitat types, primarily sandy deserts (Gertsch and Allred 1965; Polis and McCormick 1986, 1987) and desert grasslands (Bradley 1986; Bradley and Brody 1984; Gertsch and Allred 1965; Jiménez-Jiménez and Palacios-Cardiel 2010), mostly in North America. Thus, predictions about scorpion importance in xeric habitats (Polis 1993) come primarily from data gathered in a limited range of habitat types and on a narrow range of ecomorphotypes. However, in recent years some studies have been conducted in the arid and semiarid areas of South America of the Arid Chaco and Caatinga (Araújo et al. 2010, Carmo et al. 2013, Nime et al. 2013).

Because a number of population- and community-level attributes, including species richness, diversity and dominance, vary among desert habitat types (Fet et al. 1998), it seems likely that the ecological importance of scorpions will also vary across habitats. Knowledge of species distribution in different habitats can help to identify the ecological characteristics of these ecosystems and to propose strategies to help restore and maintain habitats for recolonization. Biodiversity studies are thus very useful in characterizing ecological communities, showing how a community shares environmental resources, and as a tool for comparing and measuring the effect of human activities on ecosystems (Halffter 1992). Similarly, one can evaluate or predict potential impacts of management practices on agro-ecosystems, the effect of livestock, or the impact of fire on the structure and function of communities, which has been explored for invertebrates (Buddle et al. 2006; Hendrickx et al. 2007; Lindsay and Cunningham 2009; Ruiz-Cobo et al. 2010; Wikars and Schimmel 2001; Sileshi and Mafongoya 2006; Teasdale et al. 2013). Such habitat modifications can have a negative impact on minor taxa such as scorpion populations, since these occupy specific microhabitats (Pande et al. 2012).

Surveys of invertebrate fauna in areas where conservation strategies already exist are especially important. Although not originally established to conserve invertebrates, resources are already in place for the conservation of potentially new, rare and endemic invertebrate species that may exist in these areas. In addition, management plans to conserve fauna can only be developed and implemented once inventories, or at least partial inventories, are completed (Whitmore et al. 2002). Quantitative documentation of biodiversity is an important aspect of ecology and a popular topic in recent times. Such diverse taxa as birds (Grigera and Pavic 2007),

butterflies (Lazzeri et al. 2011) and amphibians (Verga et al. 2012), have been recently studied in Argentina. However, biodiversity studies of invertebrate groups like arachnids are scarce. The scorpion fauna of Argentina as a whole has been worked out (Ojanguren-Affilastro 2005); however, previous studies were restricted to qualitative data collection and analysis and publication of checklists of various regions, and were undertaken for purposes other than biodiversity assessment (Acosta 1993, 1995a, b). Particularly, little is known about the composition of scorpion communities in Chaco ecosystems, with the exception of a recent study in the Arid Chaco ecoregion that focuses on the influence of environmental variables on the surface activity of scorpions (Nime et al. 2013).

The Arid Chaco ecoregion (NT0201 in Olson et al. 2001) is the second largest arid zone of America (after the Cerrado ecoregion), covering 786,790 km<sup>2</sup> of western and north Argentina, western Paraguay and southern Bolivia. This study is one of the few intensive projects about the diversity of scorpions in the Arid Chaco ecoregion using pitfall traps and UV light as sampling methods. The Chancaní Reserve was chosen as a sample of the Arid Chaco ecoregion, as it presents the highest number of sympatric scorpions recorded in Argentina (9 species in 2 families: 6 Bothriuridae and 3 Buthidae) (Acosta 1995b). Most scorpion species there are ground-dwelling species, eight of them being active during the summer and one in the winter. Bothriurids in general live in burrows that they dig, while many genera of buthids live almost exclusively under logs, rocks or tree bark (Polis 1980).

The goal of this research was to examine the assemblage of scorpions from two different habitats, mature and secondary forest, within a Chaco ecosystem in central Argentina. We describe basic populations (surface activity, sex ratio) and community level attributes (surface activity, species richness and diversity) for each assemblage.

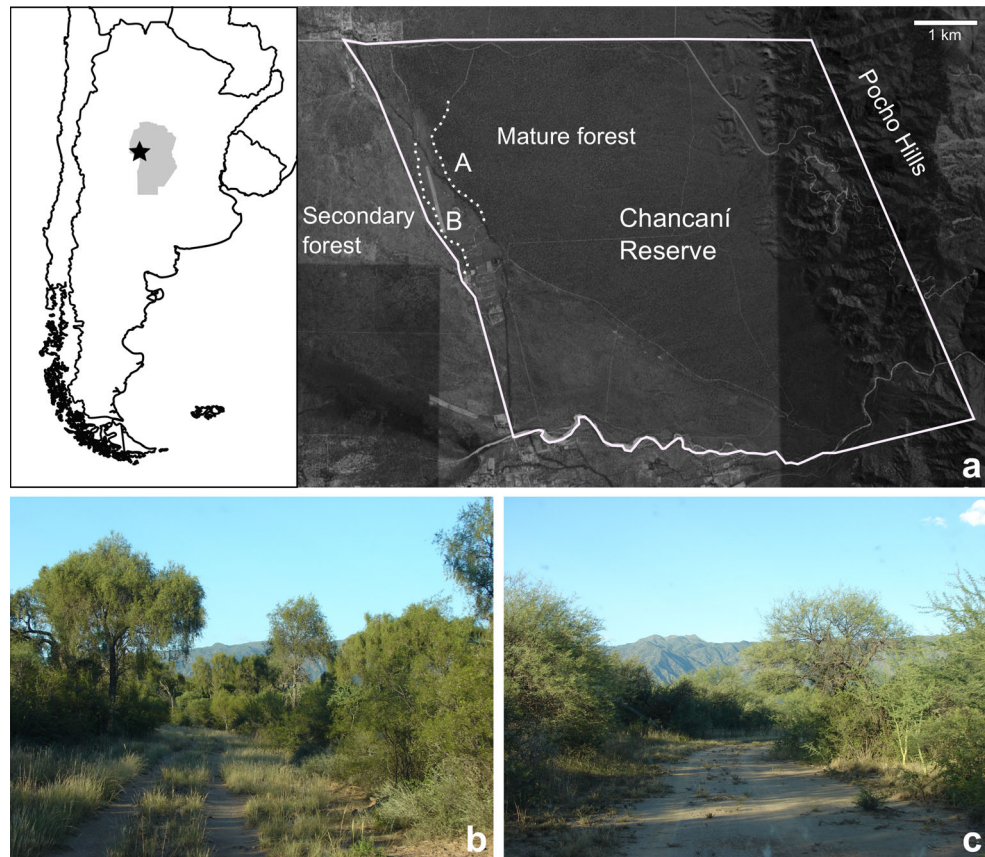
## Materials and methods

### Study site

The study was conducted in the Parque Provincial y Reserva Forestal Chancaní (Chancaní Reserve, 31°22'13.21" S 65°27'13.75" W, 4,960 ha). The reserve is located in the southernmost portion of the Chaco (Arid Chaco ecoregion, NT0701 in Olson et al. 2001) in Córdoba province, Argentina (Fig. 1a). For a more complete description of the study site, see Nime et al. (2013).

The fire season in the Chaco ecoregion usually coincides with the frost, from May to September (Kunst and Bravo 2003). In December 1994, an out of season, high-intensity wildfire affected the reserve, starting under extremely dry

**Fig. 1** **a** Location of the Chancaní Reserve in Argentina (star, Córdoba Province in gray) and sampling areas (transects sampled indicated by *dashed lines*: *A* mature forest; *B* secondary forest). **b** Mature forest. **c** Secondary forest. More vegetation and vertical strata can be observed in mature forest than in secondary forest



conditions because the start of the rainy season was much delayed. The fire affected about 32,000 ha of Chaco forest, 230 ha of which are within the western boundaries of Chancaní Reserve. The fire generated a secondary forest area beside the main forest area (Fig. 1a–c), which provides a unique situation for improving our understanding of the relationship of habitat disturbance and wildlife.

The increasing degradation of the Chaco forest and the lack of well-preserved mature forest in the region made the unburned (mature forest) (Fig. 1a, b) and burned (secondary forest) (Fig. 1a–c) areas unique in terms of management history. We were therefore unable to sample truly replicated plots (*sensu* Hurlbert 1984) or extrapolate results beyond the areas surveyed but, despite this, our design had some singularities that made it possible to assess the indirect effects of the 1994 fire in the areas sampled: (a) there was a known management history for both the burned and the unburned areas; (b) vegetation in both areas was similar before the fire, and (c) the burned and unburned areas are geographically close, thus avoiding biasing in results due to local variations in climate (in Pelegrin and Bucher 2010). Stands in mature forest are close to climax conditions and Pelegrin and Bucher (2010) found that fourteen years after the fire, vegetation in the burned (secondary forest) and unburned areas (mature forest) was still markedly different.

#### Sampling design

Two sites were selected within Chancaní Reserve (Fig. 1a), representative of the mature forest (Fig. 1b) and the secondary forest (Fig. 1c). Fifteen transects (50 m × 6 m) were established on each site, separated from each other by 70 m (intertransect). The transects were along and on the main sector pathways, for practical reasons because it is difficult to access and observe scorpions in dense forest. Pathways in each site were located as close together as possible, separated between 230 and 760 m, to avoid any possible effect of soil differences on the scorpion communities. Scorpion diversity and abundance has been seen to change in the Chancaní Reserve towards the eastern hills, from typical Arid Chaco species to species more commonly found in rocky environments (Acosta 1995b).

Sampling consisted of walking along the transect with a Maglite® flashlight modified with ultraviolet (UV) LED attachments. UV irradiation causes scorpions to fluoresce, making almost all species of scorpion easily detectable in the dark (Honetschlager 1965). Scorpions located were classified by species and sex–age class (male, female and juvenile) with a field stereoscopic magnifier and then released in the same place.

**Table 1** Number of scorpion sampling nights with UV light and pitfall traps methods in mature and secondary forest in Chancaní Reserve, in the months of November, December, January and February

Site	Nov 2009	Dec 2009	Jan 2010	Nov 2010	Dec 2010	Jan 2011	Feb 2011	Total
Mature forest (UV)	8	3	3	3	3	3	3	26
Secondary forest (UV)	8	3	3	3	3	3	3	26
Mature forest (Pt)	13	6	7	8	8	6	6	54
Secondary forest (Pt)	13	6	7	8	8	6	6	54

UV UV light method, Pt pitfall traps method

Pitfall traps were also used for sampling. Five plastic containers (8 cm diameter  $\times$  11 cm depth) were placed at the side of the pathway at each intertransect, buried flush with the soil surface and each containing 300 cm<sup>3</sup> of saturated saline. The five traps alternated right and left of each intertransect, totalling 75 traps per site. They remained the same number of nights per site, but the number of nights differed per month (Table 1). Their contents was emptied and transferred to ethanol 80 %. Scorpions were classified by species and sex–age class.

Sampling lasted about 2 h after dusk (from 9 pm to about 11 pm) which are the main hours of scorpion activity (Nime, pers. obs.). Sampling was conducted during the periods: (1) November 2009 through January 2010 (14 nights–28 person hours, per site), (2) November 2010 through February 2011 (12 nights–24 person hours, per site). The sampling effort was the same at each site on each recording night (2 h/night), with a total of 26 nights per site with the UV light method, and pitfall traps placed at each site on a total of 54 nights (Table 1).

The sampling effort with the UV light was the same every month except for November 2009 when it was increased (8 nights per site) in order to observe the effect of moonlight on scorpion activity (Nime et al. 2013). Therefore, for comparative analyses of surface activity of scorpions between sites and months with the UV light method, we selected sampling of 3 nights in November 2009, choosing the nights with the same criteria as the remaining months (during new moon periods or near this period) so that comparisons are made using the same sampling effort. In the pitfall traps method, sampling days varied from 6 to 13 days per month. For analysis with this method, we created variable days, introduced as a covariate to account for the difference in effect sampling between months. However, for comparisons of scorpion diversity among sites, we used the total data (both methods).

#### Statistical analysis

##### Surface activity

For each site and for each method (UV light and pitfall traps), surface activity was estimated as the number of

scorpions captured (abundance). Surface activity of all scorpions (all species abundance pooled) at each site was compared. Analyses were conducted with InfoStat (Di Rienzo et al. 2013). Surface activity of scorpions was modeled using a Generalized Linear Mixed Model interface with R-packages (R Core Team 2013) (glmer function). Surface activity (abundance) was used as a variable, site, month and transect as classification criteria, site, month and their interaction (site\*month) as fixed factors, and transect as a random effect. Surface activity of the most abundant species was analysed in the same way. We assumed a Poisson distribution with a log-link function. Significance was set at  $p < 0.05$ . To compare means, we used the Fisher's least significant difference test (LSD).

General sex–age class ratios (males:females:juveniles) observed with the UV light method for the most common species in this study, *Brachistosternus ferrugineus* (Thorell, 1877) and *Timogenes elegans* (Mello-Leitão, 1931), were calculated by site and month.

##### Diversity of scorpions: species richness, Shannon and Jaccard indices

To calculate the species richness of scorpions, Shannon Index and Jaccard coefficient, we included data taken by both methods (UV light and pitfall traps). The  $\alpha$ -diversity of scorpions across habitats was calculated using species richness (S) and Shannon index of diversity (Magurran 1988). Species richness was calculated as the number of scorpion species at each site. We calculated the Shannon Index ( $H'$ ) for each transect-intertransect, adding the values of abundance from each transect and intertransect for all months and obtaining  $n = 15$  (transect-intertransect) for each site. Differences in Shannon Index between sites were analysed with the  $T$  test, due to the normality of this variable. Analyses were conducted with InfoStat/Professional version 2011p (Di Rienzo et al. 2013) using significance level  $p < 0.05$ .

The  $\beta$ -diversity was calculated as similarities between communities by the Jaccard coefficient:  $C_s = c/(s_1 + s_2 - c)$ , where  $s_1$  and  $s_2$  are the number of species of communities 1 and 2 and  $c$  is the number of species in both communities (Moreno 2001).

**Table 2** Scorpion species sampled at the mature forest and secondary forest study sites in Chancaní Reserve, using UV light and pitfall traps methods

Scorpion species	UV light				Pitfall traps				Total	
	Mature forest		Secondary forest		Mature forest		Secondary forest		N	%
	N	%	N	%	N	%	N	%		
<i>Brachistosternus ferrugineus</i>	691	85.73	544	81.80	127	51.63	109	44.13	1,471	74.90
<i>Brachistosternus pentheri</i>	0	0	53	7.97	1	0.41	9	3.64	63	3.21
<i>Timogenes elegans</i>	45	5.58	41	6.17	97	39.43	120	48.58	303	15.43
<i>Timogenes dorbignyi</i>	18	2.23	4	0.60	14	5.69	5	2.02	41	2.09
<i>Bothriurus cordubensis</i>	7	0.87	6	0.90	3	1.22	2	0.81	18	0.92
<i>Zabius birabeni</i>	43	5.33	17	2.56	4	1.63	2	0.81	66	3.36
<i>Tityus confluens</i>	2	0.25	0	0	0	0	0	0	2	0.10
Total	806	100	665	100	246	100	247	100	1,964	100

Numbers are given as specimens recorded (N) and percentage of the total (%)

## Results

### Surface activity in study area

During the study period, with both methods of capture at the two sites, we found 1,964 scorpions representing 7 species within 5 genera in 2 families (Bothriuridae and Buthidae). The following species were found: *Brachistosternus ferrugineus*, *Brachistosternus pentheri* Mello-Leitão, 1931, *Timogenes elegans*, *Timogenes dorbignyi* (Guérin-Méneville, 1843) and *Bothriurus cordubensis* Acosta, 1995 (Bothriuridae); *Zabius birabeni* Mello-Leitão, 1938 and *Tityus confluens* Borelli, 1899 (Buthidae). UV light sampling provided far more data than the pitfall traps method; the former yielded 1,471 scorpions and the latter 493. Bothriuridae represented 96.5 % of the total material examined and the remainder was Buthidae (3.5 %). The proportion between the various species varied. *Brachistosternus ferrugineus* was the most common species sampled with UV light in all months, accounting for 85.73 and 81.80 % in mature forest and secondary forest, respectively (Table 2). *Timogenes elegans* was the most common species sampled with pitfall traps in secondary forest (48.58 %), followed by *B. ferrugineus* (44.13 %), and the second most abundant in mature forest (39.43 %) after *B. ferrugineus* (51.63 %). *Tityus confluens* was the least common species of the total number of collected scorpions and was found only in mature forest with the UV light method (n = 2; 0.25 %) (Table 2).

### Surface activity of all scorpions

#### UV light method

We found a significant month by site interaction ( $\chi^2 = 37.16$ ,  $p < 0.0001$ ) for counts of scorpions with surface activity. We found a significant month effect ( $\chi^2 = 80.50$ ,  $p < 0.0001$ ) but no significant site effect

( $\chi^2 = 2.59$ ,  $p = 0.1077$ ); however, the presence of interactions meant it was not possible to see the effect of each factor separately and so we present the means for the combined effects (Table 3). To observe this interaction, mean graphics were performed by site and month, expressed as average number of scorpions by transect (Fig. 2). In some months, we observed significantly more individuals in the mature forest than in secondary forest. February 2011 is the only month that we observed significantly higher activity in the secondary than in the mature forest (Fig. 2).

#### Pitfall traps method

We found a significant month by site interaction ( $\chi^2 = 21.87$ ,  $p = 0.0013$ ) for counts of scorpions with surface activity. We found a significant month effect ( $\chi^2 = 3293.7472$ ,  $p < 0.0001$ ) but no significant site effect ( $\chi^2 = 0.0048$ ,  $p = 0.945$ ). We present the means for the combined effects (Table 3). To observe this interaction, mean graphics were performed by site and month, expressed as average number of scorpions by intertransect (Fig. 3). December 2009 and January 2011 were the most abundant months at both sites and February 2011 in the secondary forest (Table 3). In most of the months, no significant difference in activity between sites was observed. However, in December 2010 and February 2011 the activity was significantly higher in the secondary forest (Fig. 3).

When differences between sites were analysed for the most abundant species, *B. ferrugineus* and *T. elegans*, similar results were obtained in both methods.

#### Sex-age specific surface activity

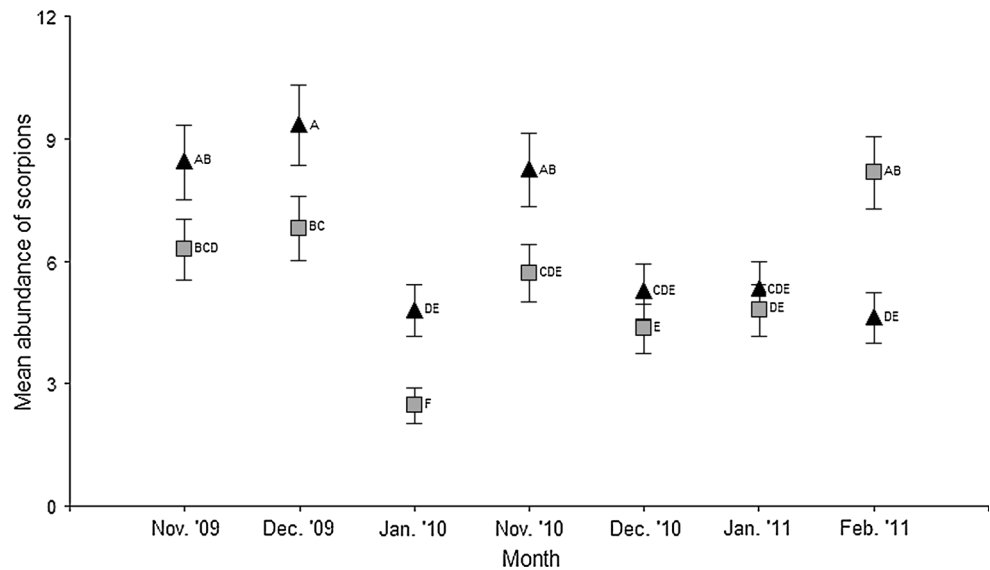
General sex-age class ratios (males: females: juveniles) observed on the surface with the UV light method was

**Table 3** Generalized linear mixed models. Relationship between surface activity of scorpions and month by site interaction observed with UV light and with pitfall traps methods in the Chancaní Reserve (Córdoba, Argentina)

UV light				Pitfall traps					
Month	Site	Mean	SE	Month	Site	Mean	SE		
December 2009	MF	9.32	0.98	A	February 2011	SF	7.39E <sup>-03</sup>	1.19E <sup>-03</sup>	A
November 2009	MF	8.42	0.91	AB	December 2009	MF	6.72E <sup>-03</sup>	1.13E <sup>-03</sup>	A
November 2010	MF	8.22	0.9	AB	January 2011	MF	6.72E <sup>-03</sup>	1.13E <sup>-03</sup>	A
February 2011	SF	8.16	0.9	AB	January 2011	SF	5.46E <sup>-03</sup>	1.00E <sup>-03</sup>	AB
December 2009	SF	6.8	0.79	BC	December 2009	SF	5.30E <sup>-03</sup>	9.86E <sup>-04</sup>	AB
November 2009	SF	6.29	0.75	BCD	February 2011	MF	3.20E <sup>-03</sup>	7.47E <sup>-04</sup>	BC
November 2010	SF	5.7	0.71	CDE	January 2010	MF	2.12E <sup>-03</sup>	3.79E <sup>-04</sup>	CD
January 2011	MF	5.31	0.68	CDE	January 2010	SF	1.54E <sup>-03</sup>	3.18E <sup>-04</sup>	DE
December 2010	MF	5.24	0.67	CDE	December 2010	SF	9.57E <sup>-04</sup>	1.57E <sup>-04</sup>	EF
January 2011	SF	4.79	0.64	DE	November 2010	MF	7.79E <sup>-04</sup>	1.40E <sup>-04</sup>	FG
January 2010	MF	4.79	0.64	DE	November 2010	SF	7.62E <sup>-04</sup>	1.38E <sup>-04</sup>	FG
February 2011	MF	4.6	0.62	DE	December 2010	MF	5.63E <sup>-04</sup>	1.17E <sup>-04</sup>	G
December 2010	SF	4.34	0.6	E	November 2009	MF	6.40E <sup>-06</sup>	1.10E <sup>-06</sup>	H
January 2010	SF	2.46	0.43	F	November 2009	SF	4.20E <sup>-06</sup>	8.00E <sup>-07</sup>	H

Mean by transect by month in each site. *MF* mature forest, *SF* secondary forest, *SE* standard error of the mean. Means with a common letter are not significantly different ( $p > 0.05$ )

**Fig. 2** Month by site interaction ( $\chi^2 = 37.16$ ,  $p < 0.0001$ ) for surface activity of scorpions in sampling with UV light method in mature forest and secondary forest, Chancaní Reserve. Mean graphics by site and month, expressed as average number of scorpions by transect ( $\pm$ SE). Common letters are not statistically different. Mature forest: black triangles; secondary forest: grey squares



different for the two most common species in this study. The general sex–age class ratio observed in all the study area for *B. ferrugineus* was 1: 1.24: 1.35 and for *T. elegans* was 1: 0.53: 0.24. However, higher activity of *B. ferrugineus* males was observed in December 2010, January 2011 and February 2011 in mature forest and in December 2010 and February 2011 in secondary forest (Fig. 4), while males of *T. elegans* were more active in January 2010, January 2011 and February 2011 in mature and secondary forest (Fig. 5).

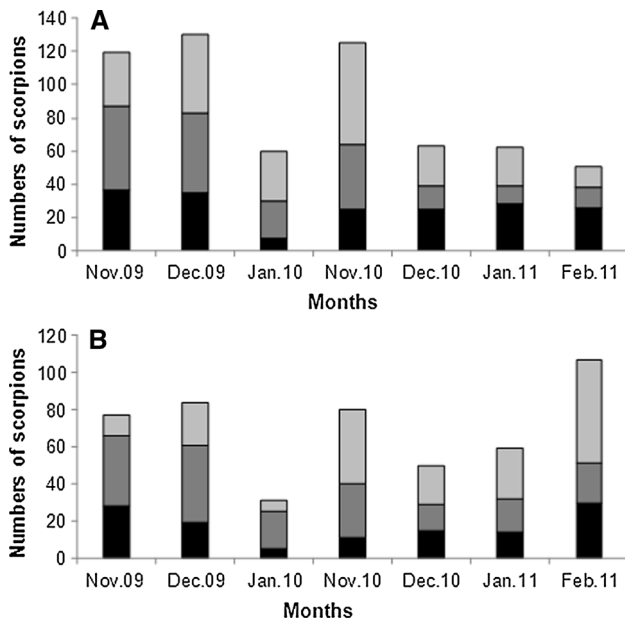
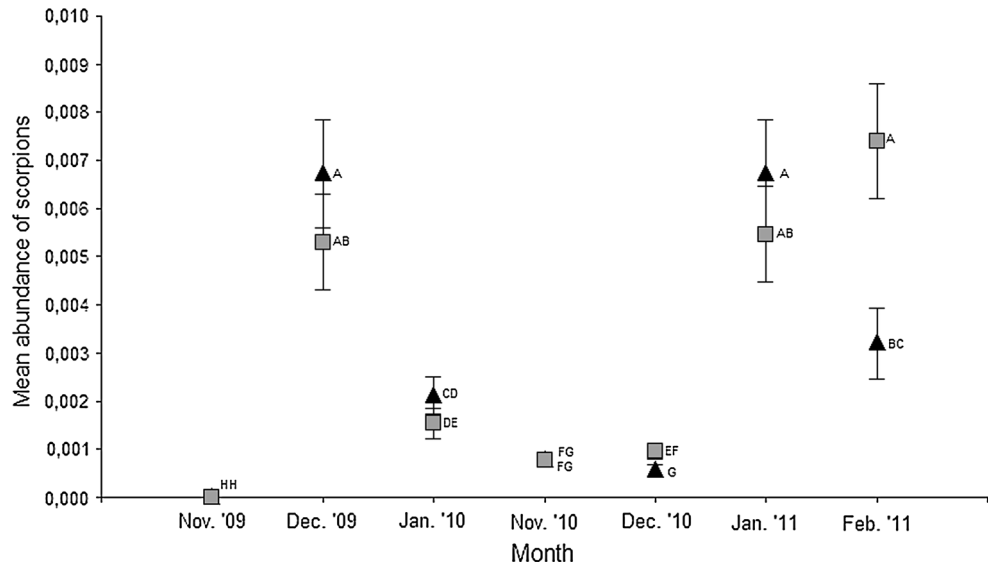
*Species richness, Jaccard and Shannon indices*

We recorded seven species in the mature forest and six in the secondary forest. The only species that was not detected in the secondary forest was *T. confluens*, which was also extremely rare in the mature forest ( $n = 2$ ) and was detected only by the UV light method.

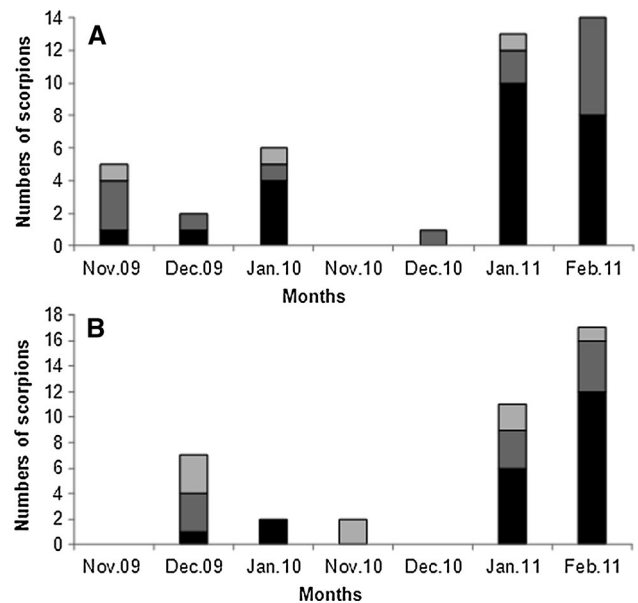
The Shannon index was not significantly different ( $t = -1.08$ ,  $p = 0.2888$ ) between mature forest ( $n = 15$ ,  $H' = 0.69 \pm 0.05$ ) and secondary forest ( $n = 15$ ,  $H' = 0.77 \pm 0.05$ ).



**Fig. 3** Month by site interaction ( $\chi^2 = 21.87$ ,  $p = 0.0013$ ) for surface activity of scorpions in sampling with pitfall traps method in mature forest and secondary forest, Chancaní Reserve. Mean graphics by site and month, expressed as average number of scorpions by transect ( $\pm$ SE). Common letters are not statistically different. Mature forest: *black triangles*; secondary forest: *grey squares*



**Fig. 4** Sex-age class ratio (males, females and juveniles) for *Brachistosternus ferrugineus* observed with UV light method per month in mature (a) and secondary (b) forest in the Chancaní Reserve (Córdoba, Argentina). Males: *black*; females: *dark grey*; juveniles: *light grey*



**Fig. 5** Sex-age class ratio (males, females and juveniles) for *Timogenes elegans* observed with UV light method per month in mature (a) and secondary (b) forest in the Chancaní Reserve (Córdoba, Argentina). Males: *black*; females: *dark grey*; juveniles: *light grey*

The Jaccard index was  $C_s = 0.86$ , indicating that both sites share 86 % of species. *Tityus confluens* was the only species not shared between sites; this was recorded only in mature forest.

It should be mentioned that, although *B. pentheri* was present at both sites, only one individual of this species was observed in the mature forest (pitfall traps method), while in the secondary forest we observed 62 individuals with both methods.

## Discussion

Habitat modification caused by the fire 15 years ago, which generated the present secondary forest, had an effect on the surface activity of scorpions, but no differences were seen in terms of species diversity. These results agree with those of Pelegrin and Bucher (2010) on lizard assemblage for the same region, finding higher abundance of lizard in the unburned than in the burned area, but that species diversity, however, was not affected.

We found that surface activity of total scorpions was higher in mature forest than in secondary forest with the UV light method for most of the months. Some species of scorpions reach their highest densities only in areas with extensive ground cover from rocks, logs, other vegetation litter, canopy density and the thickness of the substrate (Cala-Riquelme and Colombo 2011; Koch 1978; Prendini 2001; Smith 1966; Stahnke 1966; Warburg and Ben-Horin 1978). This higher abundance could be due to characteristics of the habitat in mature forest that favour a high density. Also, the presence of a higher stratum compared to secondary forest could be influencing scorpion abundance by providing a better foraging area where moonlight cannot reach easily (Nime et al. 2013). However, an exhaustive analysis of the habitat characteristics should be conducted in the future to be more accurate. This greater activity in mature forest is observed only with the UV light, and no significant differences were observed with pitfall traps, possibly due to the lower number of scorpions found by this method. Both methods noted higher activity in the secondary forest than in mature forest in February 2011. Interestingly, a high rainfall was recorded in this summer, which might have affected scorpion observation with UV light or hindered the fall of scorpions in the traps due to the overgrowth of vegetation in the mature forest.

*Brachistosternus ferrugineus* was the most commonly collected species at both sites with UV light but had higher surface activity in mature forest, with the exception of February 2011, when the greatest abundance was in the secondary forest, coinciding with the surface activity results for all scorpions. In Argentina, species of the genus *Brachistosternus* are dominant in xeric environments of the west and south of the country, often forming large populations that are generally more abundant than other species found in sympatry (Ojanguren-Affilastro 2005). *Brachistosternus ferrugineus* is the most common species in the Chaco phytogeographical province (Acosta 1995b). Scorpions of this genus usually live in areas with fairly loose, usually fine or sandy substrate, where they build galleries that do not usually exceed 30 cm deep (Ojanguren-Affilastro 2005). *Brachistosternus penteri* was more abundant in secondary forest (62 individuals) than mature forest (1 individual). This is a psammophilic species, which is common in Monte habitats (drier shrub plains, from western Argentina), and is only occasionally found in Chaco environments (Acosta, 1995a; Ojanguren-Affilastro, 2005). It prefers finer substrates, and it appears that the modification of the forest and soil produced by fire offered an opportunity for *B. penteri* to expand its distribution (Acosta, 1995a). These results are consistent with findings in Chancaní (Acosta, Peretti and Mattoni, unpublished in Acosta, 1995a) that *B. penteri* is more frequent along roads and in deforested areas than in undisturbed areas.

*Timogenes elegans* was the most common species sampled with the pitfall traps method in secondary forest (48.6 % of the individuals) and the second most abundant in mature forest (39.4 %) after *B. ferrugineus* (51.6 %). However, no significant differences were detected in surface activity of *T. elegans* between both sites with the pitfall traps method, with higher activity in the secondary than in mature forest only in February 2011. The genus *Timogenes* is a key element of the wildlife of scorpions of the Chaco region. Species of this genus are known to usually live in areas with loose substrate, between fine and sandy, where they build their galleries.

*Tityus confluens* was the least common species ( $n = 2$ ; 0.1 % of the total number of collected scorpions) and was observed only in mature forest with the UV light method. This species is rare and, when present, is always in low numbers (Acosta 1995a). It is a typical element of scorpiofauna of the Chaco, inhabiting areas of Argentina, Bolivia, Paraguay and Brazil (Bertani et al. 2005; Ojanguren-Affilastro 2005). In Argentina, most of the localities where *T. confluens* has been collected are in the dry western Chaco, with lower penetration in the humid Chaco; some of the most westerly distribution corresponds to the Monte phytogeographic province or the ecotone between this and the Chaco (Ojanguren-Affilastro 2005). *Tityus confluens* seems to adapt well to urban environments, being very common in cities of northern Argentina (Lourenço and Aparecida Da Silva 2007; Ojanguren-Affilastro 2005).

*Bothriurus cordubensis* was also found in low numbers ( $n = 18$ ; 0.92 % of the total number of scorpions collected). This species inhabits hilly areas of central Argentina, and in some provinces also penetrates marginally in areas outside the phytogeographic Espinal province (Acosta and Peretti 1998). It has also been collected in localities belonging to the phytogeographic province of Chaco (Ojanguren-Affilastro and Vezzani 2001). It seems evident that the greater the distance from the mountains, the fewer individuals are detected (Acosta 1995a). This could explain the low number of specimens found at both sites.

In contrast to surface activity, species richness was similar between the two sites, with only one species captured exclusively in the mature forest, *T. confluens*, but in extremely low density. We can assume therefore that this species was not found in the secondary forest for this reason and we cannot assert that this species is present only in the mature forest. Generally, species richness declined with increasing habitat modification (Canaday 1996; Marshall and Swaine 1992; Whitmore and Sayer 1992), although richness in some groups is surprisingly insensitive to extreme habitat modification, and not all taxa had maximum species richness in near-primary or old-growth secondary sites (Lawton et al. 1998), and some species may

even be favoured by habitat modification as occurred with *Brachistosternus pentheri*.

Attempts to assess the impact of habitat modification using changes in species richness may be highly misleading (Lawton et al. 1998). Several other studies also cast serious doubt on the utility of indicator species to predict changes in species richness (Oliver and Beattie 1996; Prendergast and Eversham 1997; Prendergast et al. 1993) presumably for the common-sense reason that different kinds of organisms have very different ecological requirements, and hence are unlikely to show similar responses to even major changes in habitat (Lawton et al. 1998). In this study, the two sites share 86 % of the species, indicating that there was no particular species assemblage at each site.

The Shannon index was low and similar at both sites, indicating low species diversity. This is due to the dominance of *B. ferrugineus*, which accounted for over 82 % of the individuals in mature forest, and for over 79 % of those in secondary forest. Low  $\alpha$ -diversity indices are obvious while studying taxa like scorpions. Scorpions are well known for their restricted movement, cannibalism, predation by nocturnal predators, habitat specificity, food size specificity, extreme climate adaptability, and adaptive radiation (Newlands 1972, 1978; Pande et al. 2004; Polis 1990). These factors, together with a longer life span than many other invertebrates, may act as limiting factors as far as species diversity is concerned (Pande et al. 2012).

In our study, we recorded only the activity of the scorpions, but without marking the specimens on successive nights a complete census is not possible. The real population sex ratio is thus unknown. However, the observed general sex ratio (males: females) with UV light in *B. ferrugineus* was slightly biased towards females 1: 1.24, while the general sex ratio of *T. elegans* was mainly biased towards males 1: 0.53.

Seasonal surface activity of mature males differs markedly from that of females in many species. For many North American species, the sex ratio of adults on the surface changes from month to month: females are more active in the spring (until June) and again in the fall (after September), whereas males are more frequent on the surface during midsummer (Warburg and Polis 1990). The biological basis of these patterns derives from life-history phenomena. In *B. ferrugineus* and *T. elegans*, the maximum surface density and the greatest proportion of males in some months occurs during the mating season, when peaks of activity are observed and there is high mobility of males. A previous study in the same area (with pitfall traps) found this higher abundance of *T. elegans* originating almost exclusively in an “explosive” increase of male activity during the February–March period (Acosta, Peretti and Mattoni, unpublished).

Although it was not a goal in this study, we note the difference observed between the two sampling methods used. One of the methods suggested by many authors as best for sampling scorpions is that of using a spotlight or UV light to search an area at night (Sissom et al. 1990; Warburg 1997). Pitfall traps have also been used to sample scorpions (Margules et al. 1994; Sissom et al. 1990; Trueman and Cranston 1997), although Sissom et al. (1990) suggest that the use of pitfall traps as well as active searching during the day yield less than one percent of the individuals observed by searching with UV light. We noticed a difference between both sampling methods, in agreement with our previous intensive, one-month study in the same area (Nime et al. 2013). The UV light method was more effective in terms of the abundance of individuals, although the sampling effort was not the same for both methods, as pitfall traps were generally placed on more nights per site than the UV light method. The number and percentages of species caught were different in both methods. Pitfall traps do not show the actual surface activity, but depend more on the behaviour of each species: wanderer species are more easily caught by the trap than sit-and-wait ones (Acosta 1995b; Cala-Riquelme and Colombo 2011). Pitfall traps show both fewer specimens and fewer species than UV light. But more strikingly, one form, *T. elegans*, showed an activity pattern that remained completely undiscovered in UV light sampling. If we had based our conclusions upon the latter method only, we would not have been able to observe the real activity of *T. elegans*, which was far lower than the dominant *B. ferrugineus*. But the traps collected almost the same amount of individuals of *T. elegans* as *B. ferrugineus*. In this study, there may be a difference in activity of *T. elegans* throughout the night, or most of the activity of the males of our sample occurred during one or more nights, and so this activity was not observed with the UV light method. Thus, pitfall traps had the advantage of pointing out a possible feature of the phenology of this species that the UV light method was unable to detect (Acosta 1995b). This could mean that the two methods are sensitive to the same fact (scorpion diversity and density) in a different fashion, and probably their results should not be compared but both methods should be used as complementary in scorpion ecology.

## Final Conclusions

We observed a reduction only of total abundance of scorpions in the secondary forest, and species diversity was not affected. In another study we observed a significant reduction of both abundance and diversity in an area highly disturbed by livestock within the reserve (Nime and

Mattoni, unpublished data). Our results could suggest that long-range natural disturbances, many years later, may not dramatically affect biodiversity and may even favour the abundance of some species.

In summary, this landscape-scale homogeneity can provide greater regional diversity. Additionally, there are many factors that determine species composition at a site and not simply habitat type. Although a possible alternative interpretation of our results is that the habitat types classified as different at the start of the study may be more similar than previously thought. Maybe the secondary forest recovered enough to maintain the community of scorpions. It has been suggested that before the period of European colonization, the typical Chaco landscape was parkland, with patches of forests intermingled with grasslands. Available evidence indicates that the balance between woody vegetation and grasslands was maintained mostly by periodic fires (Bucher 1982). As with lizards (Pelegrin and Bucher 2010), perhaps scorpions can cope well with the disturbance produced by these periodic fires.

We do not argue against the critical importance of undisturbed forest for many species. Maximum diversity in tropical forest will be conserved by maintaining a mosaic of habitats, including large tracts of primary and secondary forest (Blockhus et al. 1992; Johns and Johns 1995). Monitoring changes in biodiversity resulting from forest modification and destruction requires a wide range of taxa to be studied, embracing species with different ecologies and life histories.

Our study provides a baseline of biological data for further demographic and broader ecological studies and emphasizes the need for impact assessment prior to undertaking developmental projects, especially since taxa like arachnids exhibit restricted movements and in general are vulnerable to habitat modification (Pande et al. 2012).

Detailed studies on scorpion fauna of Argentina, including various ecological aspects such as population estimates, diversity, distribution, abundance, biogeographic and demographic changes, microhabitat preferences, etc. are necessary to fully understand the potential threats to scorpion fauna and to direct conservation efforts. In general, conservation must address the overwhelming threats to habitat loss and high level disturbance, by assuring the stability of protected areas and by defining new protected areas.

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