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ECOSYSTEMS

The isolated rocky outcrops of northeastern Argentina and their role on the herpetofauna conservation

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Abstract: Isolated rocky outcrops represent biodiversity centers, refuges for endangered species, and favorable scenarios for endemism. Most studies in these ecosystems have been focused mainly on their flora and secondarily on different groups of animals. To highlight the value of rocky outcrops as ecosystems for biodiversity conservation, in the present study, we describe the diversity of herptiles of three isolated rocky outcrops of northeastern Argentina and compare it with that of other natural areas of the region. We conducted fieldwork from September 2010 to March 2017. We calculated the alpha diversity and the number of rare, threatened and endemic species. For comparative diversity analysis, we calculated the importance of each area for amphibians and reptiles and the beta diversity. Were recorded a total of 56 species (23 amphibians and 33 reptiles), representing 35% of the herptiles recorded for Corrientes province. These species included 19 rare species, seven threatened species, and two endemic species. The overall beta diversity showed considerably differences in species composition between the compared areas. The rocky outcrops showed higher importance for amphibians and reptiles than the other areas studied. Our study contributes to the knowledge of rocky outcrops and highlights their importance in biodiversity conservation.

Key words: Argentina, biodiversity, herptiles, inselbergs.

INTRODUCTION

Rocky outcrops are a type of isolated ecosystem on the mainland, found in many parts of the world, constituted by a diverse set of isolated rock habitats and recognized as biogeographic islands (Porembski & Barthlott 2000, Fitzsimons & Michael 2017). Rocky outcrops vary in height and size, degree of isolation, nature of the rocks, geomorphology and geological genesis (Twidale 1995, Watson 2002, Michael et al. 2010a). These varied physical characteristics lead rocky outcrops to present singular environmental conditions that are entirely different from those of their surrounding matrix (Coor et al. 1993, Porembski & Barthlott 2000, Burke 2003). Thus, rocky outcrops develop a variety of exclusive microhabitats where life experiences evolution in isolation, a fact that makes these ecosystems “real evolutionary laboratories” (Kristensen & Frangi 1995, Mares 1997, Porembski et al. 1998, Porembski & Barthlott 2000, Cajade et al. 2013a).

Isolated rocky outcrops are spatially discrete and maintain their typical attributes independently of their geographic location, making them interesting models to perform comparative studies in biodiversity and environmental changes at both local and global scale (Porembski & Barthlott 2000). Due to their great variety and global distribution in different climatic regions, these ecosystems constitute essential landscape elements that play a role in generating and maintaining biodiversity in addition to providing key ecosystem services (Porembski et al. 2016). Rocky outcrops thus represent centers of biodiversity, refuges for endangered flora and fauna, and favorable scenarios for endemism and relict populations (Martinelli 1989, Porembski et al. 1997, 1998, Burke 2003, Fredericksen et al. 2003, Porembski 2007, Cajade et al. 2013a). Thereby, studies on these ecosystems provide fundamental knowledge to understand the relationship between local, regional and global biodiversity, the relationship between biodiversity and ecosystem function, and the effects of habitat fragmentation on ecological, biogeographical and evolutionary processes (Porembski & Barthlott 2000, Burke 2003, Michael et al. 2008).

Despite their highlighted importance, isolated rocky outcrops represent one of the least studied ecosystems (Porembski & Barthlott 2000, Burke 2003, Porembski 2007). However, in the last 20 years, several studies demonstrated their importance in nature conservation (Fitzsimons & Michael 2017, Michael & Lindenmayer 2018). Most of these studies focused primarily on their flora (Hopper et al. 1997, Anderson et al. 1999, Porembski & Barthlott 2000, Burke 2003, Speziale & Ezcurra 2014) and secondarily on different animal groups such as mammals (Mares 1997, Galende & Raffaele 2013) and birds (Fredericksen et al. 2003, Fandiño et al. 2017). In contrast only a few focused on amphibians and reptiles (Conant & Collins 1991, Köhler & Böhme 1996, Michael et al. 2008, 2010b, c). The results of these studies showed that isolated rocky outcrops offer to reptiles favorable conditions for thermoregulation, food, particular habitats and refuge against predators (Fredericksen et al. 2003, Michael et al. 2008, 2010a, b, c, Cajade et al. 2013a). In addition, breeding sites such as rock pools are available for amphibians (Köhler & Böhme 1996, Mares & Seine 2000, Fredericksen et al. 2003, Mageski et al. 2014, Michael & Lindenmayer 2018).

In Argentina, isolated rocky outcrops have been poorly explored and most studies focused on their floristic diversity (Parodi 1943, Cabido et al. 1990, Kristensen & Frangi 1995, Meregalli 1998, Ravenna 2003, 2009, Beeskow et al. 2005, Speziale & Ezcurra 2012, 2014, Cantero et al. 2016). In the last ten years, a group of three isolated rocky outcrops of Paraje Tres Cerros, Corrientes, Argentina, have been explored through an interdisciplinary program of several projects to study their biodiversity. As a result, two endemic animals were described: the gecko *Homonota taragui* Cajade, Etchepare, Falcione, Barrasso & Álvarez 2013, and the scorpion *Tityus curupi*, Ojanguren-Affilastro, Adilardi, Cajade, Ramírez, Ceccarelli, & Mola 2017. Also, three species of endemic plants are known from the area (*Gymnocalycium angelae* Meregalli 1998, *Amaryllis euriphylla* Ravenna 2003, and *Cypella trimontina* Ravenna 2009). Besides, other studies pointed out the importance of these ecosystems in the conservation of spiders (Nadal et al. 2018), butterflies (P. Gervazoni, unpublished data), birds (Fandiño et al. 2017), bats (A. Argoitia, unpublished data), herptiles and plants (Cajade et al. 2013a). The knowledge generated increased the conservation value of these isolated rocky outcrops and provided the basis for the development of new research in the ambitious search of understanding the big picture of the ecosystems functioning of rocky outcrops.

Captivated by the singularity of these rocky ecosystems and motivated by the opportunity to discuss their role in amphibians and reptiles conservation and thus contribute to its valorization, we describe the herpetofauna diversity of the isolated rocky outcrops of Paraje Tres Cerros, Corrientes, Argentina. To this end, we described the herpetofauna of these rocky outcrops and their surrounding pediments, and analyzed its conservation role carrying out a comparative analysis with the herpetofauna of plain natural areas of Corrientes province.

MATERIALS AND METHODS

Study area

We carried out fieldwork in the isolated rocky outcrops of Paraje Tres Cerros (PTC, hereafter) located in the east-central region of Corrientes province, Argentina (Fig. 1). The region belongs to the Ñandubay District of the Espinal phytogeographic province (Cabrera 1971, Cabrera & Willink 1980). The climate is humid subtropical, with a mean annual temperature of 19.5 °C and a mean annual rainfall between 1300 and 1500 mm (Carnevali 1994). The topographic relief presents three isolated rocky outcrops that rise above the surrounding flat floodplains, forming isolated ecosystems (Fig. 1). The outcrops consist of quartz

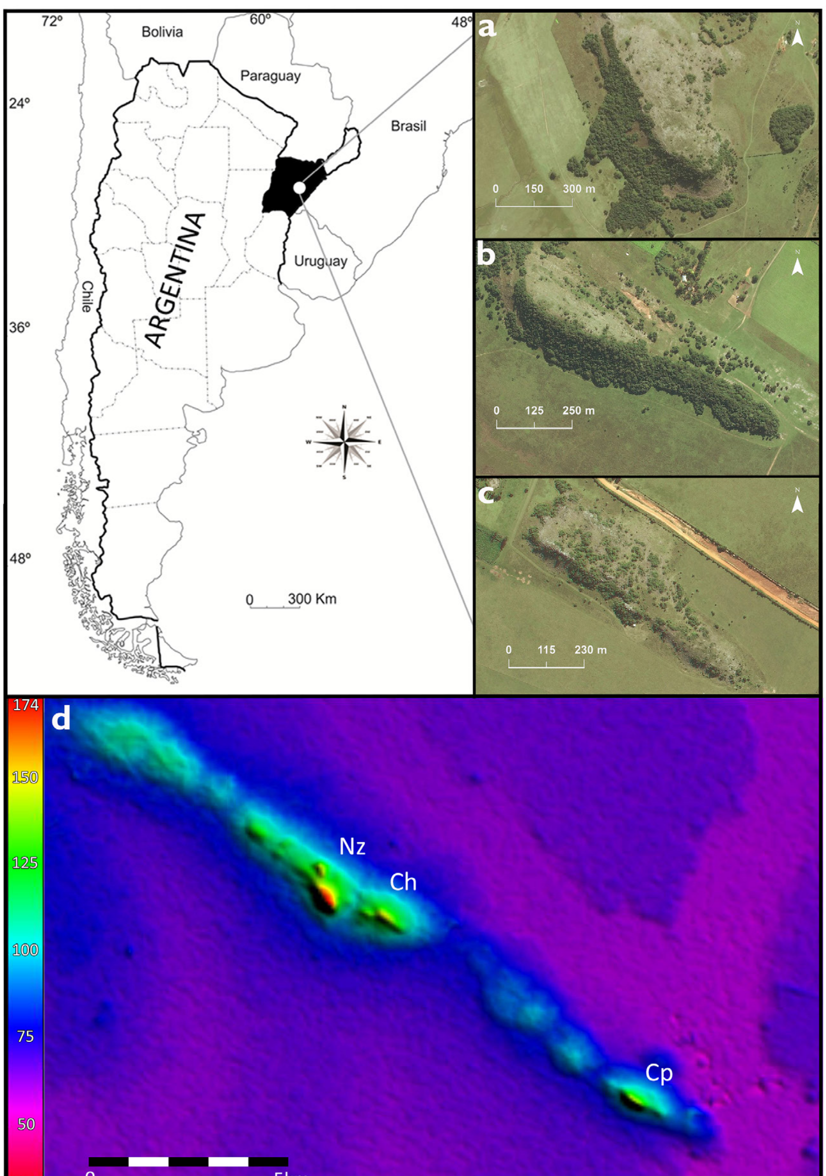

Figure 1. **Isolated rocky outcrops of Paraje Tres Cerros, Corrientes, Argentina. View of the three hills Nazareno (a), Capará (b), Chico (c), Digital elevation model (SRTM image) (d). Nz: Nazareno; Ch: Chico; Cp: Capará.**

sandstone rocks dating from the Late Jurassic to the Early Cretaceous period (Herbst & Santa Cruz 1999) and belong to the Botucatu "desert" stratigraphic formation (Aceñolaza 2007). The rocky outcrops are composed by three hills: Nazareno (29°0.6´26.51"S 56° 55´56.90"W, 179 m a.s.l., 83 ha), Capará (29°0.9´14.00"S 56°51´44.5"W, 158 m a.s.l., 79 ha), and Chico (20°0.6´45.74"S 56°55´7.78"W, 148 m a.s.l., 34 ha) (Fig. 1). The distance between Chico and Nazareno is one kilometer, and six kilometers between Chico and Capará, and they are the unique hills of the region. They are dome-shaped with a topographic SE-NW orientation, which defines a north and a south slope in each of them (Aceñolaza 2007). The northern slopes are characterized by higher sun incidence and warm winds, which make them dry environments. The vegetation in these slopes is composed of rocky grassland with sparse shrub and grasses. In contrast, the southern slopes are characterized by lower sun incidence and are exposed to humid and cool winds, accumulating a greater humidity in the environment. The vegetation in these slopes consists of a hygrophilous forest constituted by floristic elements of the Paranaense forest, although diminished in terms of species richness (Parodi 1943). In contact with the base of the rocky outcrops, there is a pediment with gentle inclination but marked with respect to the surrounding plain (Iriondo & Kröhling 2008). The pediment is characterized by a grassland habitat and the presence of small patches of hydrophilic forest, small streams, lagoons, and artificial water ponds such as cutwaters. The floodplains that surround the outcrops and the pediments are represented by a mosaic of hydrophilic natural grassland fragmented by monocultures of pines and eucalyptus trees.

Inventory sampling method and analyses

From September of 2010 to March of 2017, we conducted 46 three-day-long campaign trips, accounting for a total of 138 days of sampling. We made diurnal samplings between 9:00-12:00 hs and 15:00-18:00 hs and night samplings between 21:00-23:00 hs. We searched for amphibians and reptiles on natural refuges, such as under rocks and logs, among vegetation, holes, and crevices, by using the methodology of "complete species inventories" to capture and record the animals (Scott 1994). The sampling effort was 16 man-hours (8 man-hours by two persons), accounting for a total of 2208 hours of sampling. The specimens were found on natural habitats and collected by hand. The sampling followed the general guidelines proposed by the Dirección de Recursos Naturales of the Corrientes province, Argentina. Voucher specimens were euthanized by a pericardial injection of a local anesthetic carticain, fixed with 10% formaldehyde, and then preserved in 70% alcohol, following the standard method established in the guide for the animal euthanasia, proposed by IACUC (The Institutional Animal Care and Use Committee). We identified the animals using dichotomous keys and guides to amphibians (Cei 1980, Zaracho et al. 2012) and reptiles (Cei 1993, Giraudo 2001). Voucher specimens were deposited in the Colección Herpetológica de la Universidad Nacional del Nordeste (UNNEC), Corrientes, Argentina (Appendix).

To analyze diversity, we built a matrix of presence/absence and calculated alpha diversity from the total species richness (S) of the rocky outcrops of PTC. In addition, we calculated the alpha diversity of the two components that constitute the rocky outcrops (Hills and Pediments). To estimate the "real" species richness, we calculated the inventory completeness by using three non-parametric estimators: incidence-based coverage estimator

(ICE), Chao 2 and Bootstrap. We used these estimators because ICE and Chao 2 are based on the incidence and use presence-absence data, and Bootstrap it does not tend to overestimate species richness in the presence of rare species. We run the analysis in EstimateS v9.1.0 software (Colwell 2013, randomized 1000 times). To indicate if the sampling effort was sufficient to capture the species richness, we calculated the sample coverage and used a sample-size-based rarefaction approach to estimate the rate of increase in species richness by increasing the number of samples. We performed this analysis with the iNEXT package (Hsieh et al. 2016) in R (R Development Core Team 2011). Finally, to characterize the herpetofauna assemblage of the rocky outcrops of PTC, we calculated rarity by using the formula: R=1-(F/M), where F is the frequency of appearance of the species and M is the number of samples taken (see Gil-Carbó 2005). The rarity values obtained were divided into quartiles, considering the rare species that were included in the third quartile (25%) of the frequency distribution, following that proposed by Gaston (1994).

Comparative diversity analysis

To give a regional framework and contextualize the biodiversity values of the rocky outcrops studied, we compared the herpetofauna of the PTC with that of other natural areas of Corrientes province, that have been well explored and have highly complete inventories: Reserva Natural Provincial Isla Apipé Grande (RNAG) (Zaracho et al. 2014), Reserva Paleontológica del Arroyo Toropí (RPAT) (Ingaramo et al. 2014), Reserva Natural del Iberá (RNI) (Alvarez et al. 2003, Giraudo et al. 2006, Etchepare & Zaracho 2009, Ingaramo et al. 2012, Etchepare et al. 2013) and Parque Nacional Mburucuyá (PNM) (Alvarez et al. 2000, Zaracho & Alvarez 2005, Cano et al. 2007). We considered three parameters for the comparisons: species richness, number of threatened species and number of endemic species. Since species richness could be influenced by the size of the area, which could, in turn, affect the number of species and individuals that each site could be harboring, we calculated the importance of each area (IA) for amphibians and reptiles. This index relates the three mentioned parameters to the total size of the area, using the following formula:

$$IA = \frac{RER}{A} = \frac{\dfrac{1 + TE + E}{\log_{10} S}}{\log_{10} A}$$

Where, RER (relative species richness) is composed of TE (the number of threatened species), E (number of endemic species) and S (species richness). A is the total size of each natural area (hectares). The higher the formula value, the greater the relative richness in relation to the size of the area.

We considered the conservation status of each species as established by the Herpetofauna categorization of Argentina (Abdala et al. 2012, Giraudo et al. 2012a, Prado et al. 2012a, b and Vaira et al. 2012). For species not evaluated in previous studies and present in the study area, we categorized them according to the SUMIN index (Reca et al. 1994) with modifications (Giraudo et al. 2012b). The role of the isolated rocky outcrops of PTC in amphibian and reptile conservation was also analyzed and discussed by a quantitative comparison of the number of endemic species.

Finally, to compare the species composition with that of other natural areas, we calculated the overall beta diversity (β_{cc}) or dissimilarity, partitioned into two additive components, species replacement (β_{-3}) and species richness difference (β_{rich}), according to the equation: $\beta_{cc} = \beta_{-3} + \beta_{rich}$ (Carvalho et al. 2012, 2013). We performed all calculations with the function 'betadiver' from the vegan package (Oksanen et al. 2011) for the R statistical language (R Development Core Team 2011). Beta diversity (β_{cc}) varied from 0 when two sites were identical in species composition to 1 when species from both sites were completely different (Colwell & Coddington 1994).

RESULTS

We found 23 species of amphibians distributed in 6 families and 13 genera, and 33 species of reptiles distributed in 11 families and 25 genera. Regarding amphibians, the families Hylidae and Leptodactylidae presented the highest species richness (n=11 and n=7 respectively), whereas the families Phyllomedusidae, Mycrohylidae, and Odonthophrynidae showed only one species. Within reptiles, the family Dipsadidae presented the highest number of species (n=19), followed by Teiidae (n=3), Amphisbaenidae (n=2) and Colubridae (n=2), and seven families (Phyllodactylidae, Gymnophthalmidae, Diploglossidae, Boidae, Viperidae, Emydidae, and Alligatoridae) had only one species (Table I). The separate analysis of the environmental units showed that eight amphibians and 14 reptiles were recorded on the hill, while on the pediment, 23 and 27 species were recorded respectively (Table I).

According to the estimators´ ICE, Chao2, and Bootstrap estimators the estimated species richness was 62, 61, and 60, respectively. The percentage of observed species for the total herpetofauna, according to the estimators, was 92% on average. The recorded amphibian species represented, on average, 99% of the estimated species, whereas reptiles represented 87% (Fig. 2). The sample coverage varied between 95 and 99% for total herpetofauna and for each group (amphibians and reptiles) separately and species. Species accumulation curves showed in all the cases a tendency to asymptote for both, hill and pediment (Fig. 3).

The rarity values showed that 19 species of the PTC (5 amphibians and 14 reptiles) are rare (Table I). The species were considered rare (included in the third quartile (25%) of the frequency distribution) when values were R≥0.84 and R≥0.96, for amphibians and reptiles, respectively. The five rare species of amphibians were: *Rhinella fernandezae*, *Boana raniceps*, *Scinax similis*, *Ololygon berthae*, and *Physalaemus albonotatus*, representing 22% of the amphibian species richness. The 14 rare species of reptiles were: *Atractus reticulatus*, *Eunectes notaeus*, *Helicops infrataeniatus*, *Erythrolamprus jaegeri*, *Lygophis anomalus*, *Phylodrias agassizii*, *Taeniophallus occipitalis*, *Thamnodynastes hypochonia*, *Xenodon dorbignyi*, *Xenodon merremii*, *Mastigodryas bifossatus*, *Ophiodes aff. striatus*, *Cercosaura schreibersii*, and *Trachemys dorbigni*, representing 42% of the reptile diversity.

Comparative diversity analysis

In amphibians, the IA showed that the PTC and RNI obtained the second highest value behind RPAT, although there were no significant differences between the values of the areas. Considering the reptiles, the isolated rocky outcrops of PTC have, in all cases, a higher value than the other natural areas analyzed. The higher differences were those between PTC and PNM and RPAT (Fig. 4).

Regarding the conservation status of the species recorded in the PTC, all amphibians are in the category “Not threatened”. In contrast, reptiles included four species categorized as “Vulnerable”, one as “Threatened”, one as “Insufficiently Known”, four as ¨Not evaluated¨ and the rest as “Not threatened” (Table I). The species evaluated here for the first time include a recently described endemic gecko species

Table I. Species recorded in Paraje Tres Cerros. Conservation Status (CS), Not evaluated (NE), Not threatened (NA), Vulnerable (VU), Threatened (AM), Insufficiently Known (IC), Rarity (Ra), Frequency (F), Pasture with rocks (Pr), Rocky (R), Rocky forest (Rf), Pasture (Ps), Forest (F), Cutwaters (C), Streams (S), Ponds (P), Lagoons (L). +Specimens not collected (photographic or visual record).

CLASS/ORDER/ FAMILY	SPECIES	CS	Ra	F	HILL									PEDIMENT					
AMPHIBIA					**Nazareno**			**Chico**			**Capará**								
ANURA					**Pr**	**R**	**Rf**	**Pr**	**R**	**Rf**	**Pr**	**R**	**Rf**	**Ps**	**F**	**C**	**S**	**P**	**L**
Bufonidae	*Rhinella diptycha*	NA	0.83	8	•									•					
	Rhinella fernandezae	NA	0.89	5							•			•					
	Melanophryniscus atroluteus	NA	0.70	14	•									•		•	•	•	
Hylidae	*Dendropsophus nanus*	NA	0.76	11												•			
	Dendropsophus sanborni	NA	0.76	11												•			•
	Boana pulchellus	NA	0.48	24												•			•
	Boana raniceps	NA	0.98	1															•
	Scinax nasicus	NA	0.59	19	•					•			•		•	•		•	
	Scinax fuscovarius	NA	0.33	31	•		•	•		•	•		•		•	•		•	•
	Scinax squalirostris	NA	0.65	16										•		•		•	•
	Scinax similis	NA	0.91	4										•				•	
	Ololygon berthae	NA	0.91	4												•			
	Lysapsus limellum	NA	0.76	11												•			
Phyllomedusidae	*Pithecopus azureus*	NA	0.76	11												•		•	
Leptodactylidae	*Leptodactylus latinasus*	NA	0.59	19	•		•	•		•	•		•	•	•	•		•	
	Leptodactylus latrans	NA	0.83	8												•	•	•	
	Leptodactylus chaquensis	NA	0.85	7							•						•		
	Leptodactylus gracilis	NA	0.70	14										•	•	•	•		
	Pseudopaludicola falcipes	NA	0.61	18												•	•	•	
	Physalaemus albonotatus	NA	0.96	2														•	
	Physalaemus riograndensis	NA	0.72	13										•				•	
Odontophrynidae	*Odontophrynus americanus*	NA	0.72	13										•	•			•	
Microhylidae	*Elachistocleis bicolor*	NA	0.61	18	•		•	•		•	•		•	•	•		•	•	

Table I. Continuation

CLASS/ORDER/ FAMILY	SPECIES	CS	Ra	F	HILL									PEDIMENT					
REPTILIA					Nazareno			Chico			Capará								
SQUAMATA					Pr	R	Rf	Pr	R	Rf	Pr	R	Rf	Ps	F	C	S	P	L
Phyllodactylidae	*Homonota taragui*	NE	0.13	40		•			•			•							
Teiidae	*Ameivula* sp.	NE	0.57	20	•	•		•	•										
	Teius oculatus	NA	0.63	17	•	•		•	•		•	•		•					
	Salvator merianae	NA	0.70	14	•	•		•	•		•	•		•	•				
Gymnophtalmidae	*Cercosaura schreibersii*	NA	0.98	1							•								
Amphisbaenidae	*Amphisbaena kingii*	NA	0.85	7	•			•			•								
	Amphisbaena trachura	NE	0.93	3										•					
Diploglossidae	*Ophiodes aff. striatus*	NE	0.96	2										•					
Boidae	*Eunectes notaeus*	VU	0.98	1												•			
Viperidae	*Bothrops alternatus*	NA	0.89	5										•		•			
Colubridae	*Mastigodryas bifossatus*	NA	0.98	1	•														
	Tantilla melanocephala	**VU**	0.93	3											•				
Dipsadidae	*Atractus reticulatus*	NA	0.96	2											•				
	Oxyrhopus rhombifer	NA	0.78	10							•			•	•				
	Helicops infrataeniatus	NA	0.98	1												•			
	Hydrodynastes gigas	NA	0.93	3												•			
	Erythrolamprus jaegeri	NA	0.98	1												•			
	Erythrolamprus poecilogyrus	NA	0.72	13				•			•				•				
	Erythrolamprus semiaureus	NA	0.93	3							•						•		
	Lygophis flavifrenatus	NA	0.91	4	•									•					
	Lygophis anomalus	NA	0.96	2										•					
	Sibynomorphus turgidus	NA	0.78	10											•		•		
	Phalotris reticulatus	**VU**	0.87	6	•										•				
	Phalotris lemniscatus	IC	0.93	3	•														

Table I. Continuation

	Philodryas aestiva	NA	0.91	4										•					
	Philodryas patagoniensis	NA	0.93	3							•			•					
	Philodryas agassizii	**AM**	0.96	2										•					
	Taeniophallus occipitalis	NA	0.98	1										•					
	Thamnodynastes hypoconia	NA	0.98	1												•			
	Xenodon dorbignyi	NA	0.96	2										•					
	Xenodon merremii	NA	0.96	2										•					
TESTUDINES																			
Emydidae	*Trachemys dorbigni* **+**	**VU**	0.98	1												•			
CROCODYLIA																			
Alligatoridae	*Caiman latirostris* **+**	NA	0.57	20												•			

(*Homonota taragui*) (Cajade et al. 2013b), a new endemic lizard in process of description (*Ameivula* sp.) (Cajade et al. 2013a), a glass snake undescribed for Corrientes, Argentina, and Paraguay (*Ophiodes aff. striatus*) (Cacciali & Scott 2012), and a worm lizard species recently cited for Corrientes province, Argentina (*Amphisbaena trachura*) (Ruiz-García et al. 2016). The assessment of conservation status showed two species in the category "Vulnerable" and two in "Insufficiently Known" (Table II). The number of threatened species between the compared areas showed that the isolated rocky outcrops of PTC and RNI have the highest percentage of threatened species (13%), followed by RNAG and PNM (11% and 4% respectively) (Table III). The RPAT does not harbor threatened species. Finally, the rocky outcrops of PTC are the only area that presents endemic herp species (*Homonota taragui* and *Ameivula* sp.) (Table III).

In all cases, the overall beta diversity for the total herpetofauna showed values higher than 50%. The values of β_{cc} were, on average, 59%. The rocky outcrops of PTC showed a higher difference in β_{cc} with RPAT and RNAG than with RNI and PNM. On average, β_{cc} values were lower than 50% for amphibians, with the highest difference with RNAG and RNI. Regarding all the other natural areas, not found exclusive species in PTC. On the other hand, the β_{cc} values for reptiles were equal to or higher than 60%. The higher difference was between PTC and RPAT and RNAG. Partitioning of β_{cc} showed that differences in species composition between PTC and the other natural areas were due to both species replacement and richness differences (Table IV). The rocky outcrops of PTC harbored the following exclusive species: *Ameivula* sp., *Homonota taragui*, *Amphisbaena trachura*, *Helicops infrataeniatus*, and *Trachemys dorbigni*.

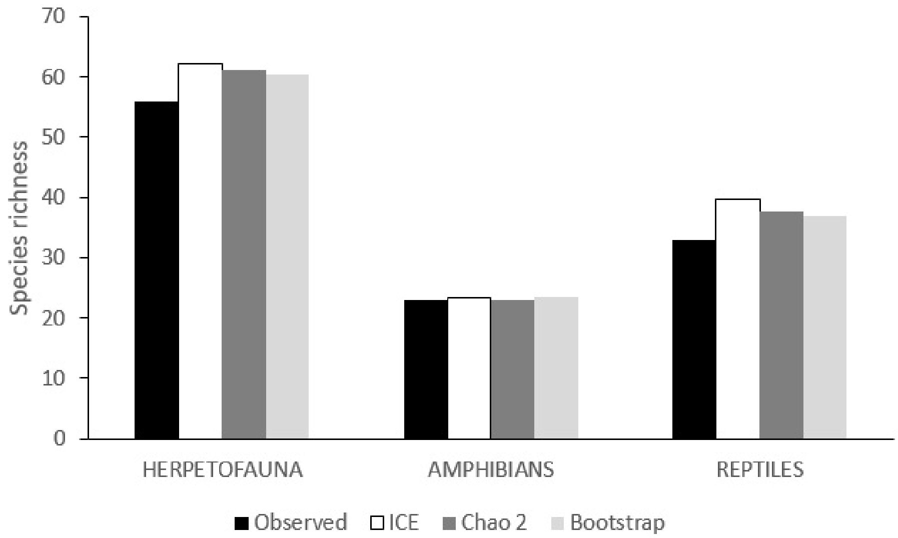

Figure 2. Non-parametric estimations of species richness for Herpetofauna, Amphibians and Reptiles of Paraje Tres Cerros, Corrientes, Argentina.

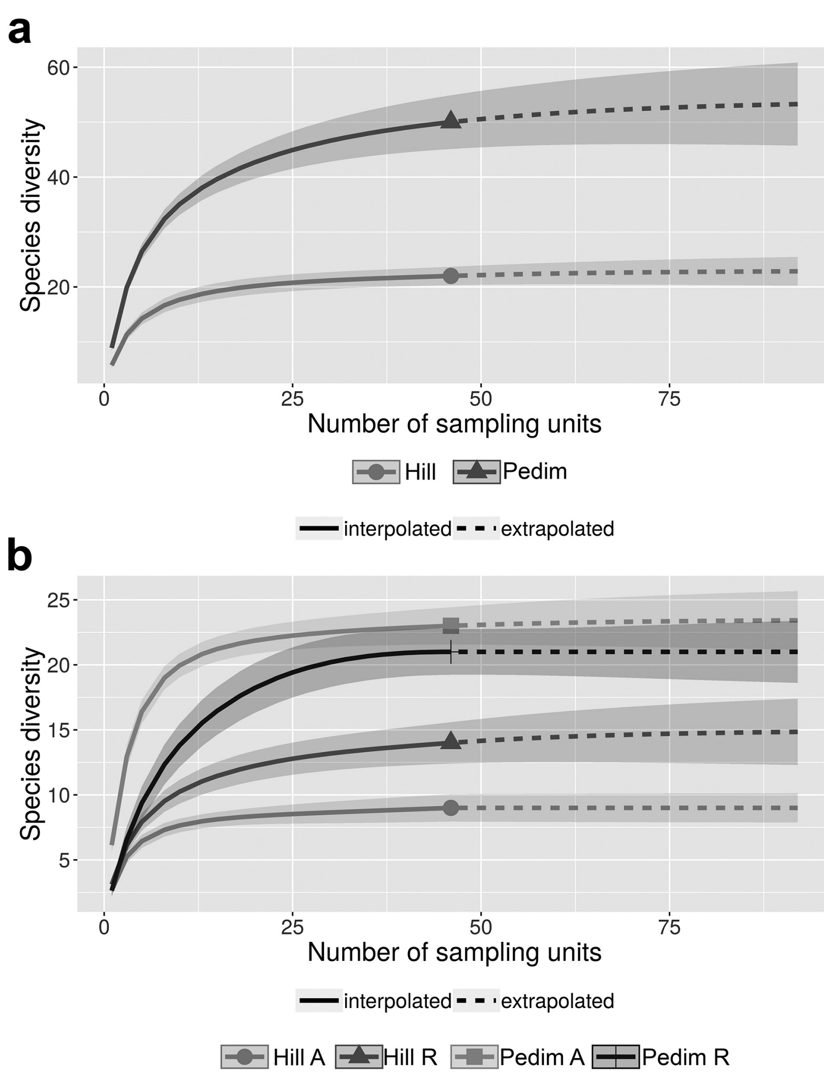

Figure 3. Species-accumulation curves for Herpetofauna (a), Amphibians, and reptiles (b). Hill A: Amphibians of the Hill, Hill R: Reptiles of the Hill, Pedim A: Amphibians of the Pediment, Pedim R: Reptiles of the Pediment.

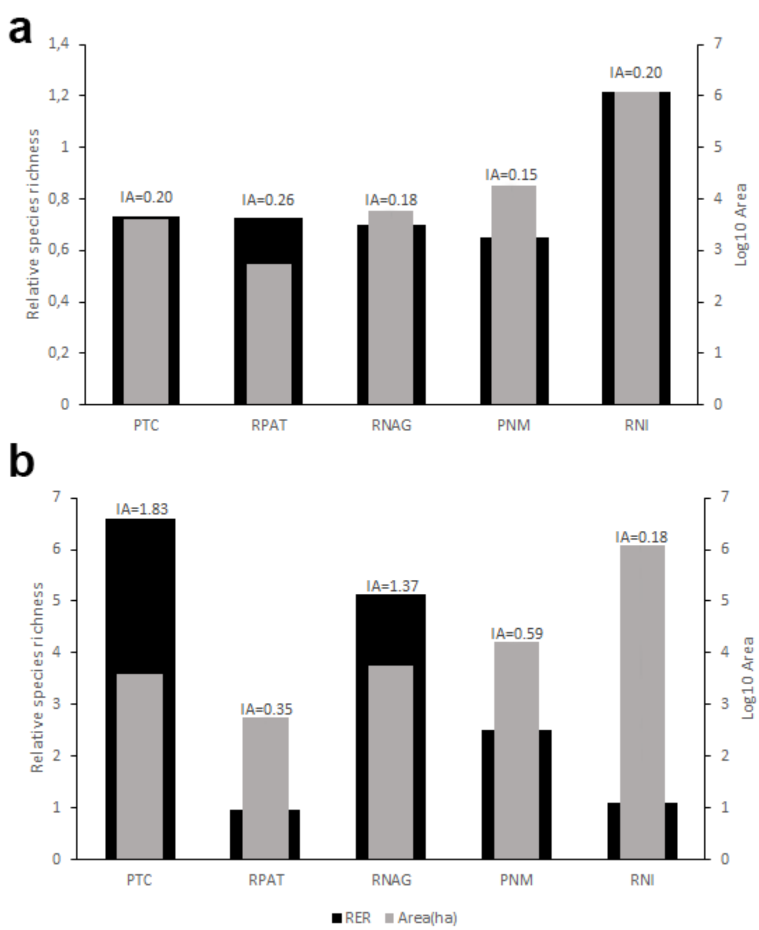

Figure 4. Comparative analysis of the importance of each area (IA) for amphibians (a) and reptiles (b) between the isolated rocky outcrops of Paraje Tres Cerros (PTC) and other areas from Corrientes province. Reserva Natural Provincial Isla Apipe Grande (RNAG), Reserva Paleontológica del Arroyo Toropí (RPAT), Reserva Natural del Iberá (RNI) and Parque Nacional Mburucuyá (PNM).

Table II. Values assigned to taxa for each variable described in Giraudo et al. (2012b). Spanish acronyms: National distribution (DINAC), Ecological rarity (RARECOL), Human effects (EFHU), Reproductive potential (POTRE), Size (TAM), Abundance (ABUND), Conservation status (CAT), Vulnerable (VU), Insufficiently Known (IC).

Variable / Species	DINAC	RARECOL	EFHU	POTRE	TAM	ABUND	VALUE	CAT
Homonota taragui	5	5	2	5	1	1	19	VU
Ameivula sp.	5	3	2	5	2	2	19	VU
Ophiodes aff. striatus	4	2	1	4	2	2	15	IC
Amphisbaena trachura	3	2	1	3	2	3	14	IC

Table III. Comparison of the herpetofauna of the rocky outcrops of Paraje Tres Cerros (PTC) and that of other natural areas from Corrientes province. RNAG: Reserva Natural Provincial Isla Apipe Grande, RPAT: Reserva Paleontológica del Arroyo Toropí, RNI: Reserva Natural del Iberá and PNM: Parque Nacional Mburucuyá.

Natural areas	Species richness	Threatened species	Endemic species	Size (ha)
PTC	56	7	2	4000
RPAT	35	-	-	554
RNAG	63	7	-	5700
PNM	74	3	-	17600
RNI	111	14	-	1230000

Table IV. **Values of the overall beta diversity (β_{cc}), species replacement (β_{-3}), and species richness difference (β_{rich}) between rocky outcrops of Paraje Tres Cerros and natural areas from Corrientes province. RNAG: Reserva Natural Provincial Isla Apipe Grande, RPAT: Reserva Paleontológica del Arroyo Toropí, RNI: Reserva Natural del Iberá and PNM: Parque Nacional Mburucuyá.**

Paraje Tres Cerros					
		RNAG	**RNI**	**PNM**	**RPAT**
Herpetofauna	β_{cc}	0.63	0.56	0.54	0.66
	β_{-3}	0.55	0.09	0.34	0.35
	β_{rich}	0.08	0.47	0.20	0.31
Amphibians	β_{cc}	0.53	0.48	0.46	0.43
	β_{-3}	0.41	0	0.16	0.40
	β_{rich}	0.12	0.48	0.30	0.03
Reptiles	β_{cc}	0.70	0.61	0.60	0.84
	β_{-3}	0.64	0.14	0.46	0.26
	β_{rich}	0.06	0.47	0.14	0.58

DISCUSSION

The species richness of the rocky outcrops of the PTC represents 35% of herpetofauna known for Corrientes province. It contains 39% of amphibians and 33% of reptiles known for this province. These percentages become important, considering that the surface of the PTC is equivalent to 0.5% of Corrientes province. High species richness has also been obtained for birds (Fandiño et al. 2017), bats (A. Argoitia, unpublished data), butterflies (P. Gervazoni, unpublished data) and spiders (Nadal et al. 2018), highlighting the importance of this particular ecosystem in the conservation of these groups of animals. Punctually, respect to the herpetofauna, rocky outcrops were signalized as favorable habitats for thermoregulation. (Köhler & Böhme 1996, Mares & Seine 2000, Fredericksen et al. 2003, Michael et al. 2008, 2010a, b, c, Cajade et al. 2013a, b, Mageski et al. 2014, Michael & Lindenmayer 2018). The rocky outcrops of PTC offer a large variety of microhabitats for reptiles, provided by the rocky substrate and its interaction with the soil and vegetation (Cajade et al. 2013a, b, M. Odriozola, unpublished data) and this abundance is in agreement with a high diversity and the presence of endemic species (this study). Contrarily, the amphibians are represented by species also distributed in the surrounding floodplains and regional matrix of the rocky outcrops of PTC (R. Cajade pers. obs.). Despite the scarce water reservoirs on the pediments and its absence on the hills, the amphibians diversity is high, but without endemic species.

Comparisons between hills and pediments showed the importance of hills, since these particular habitats for endemic and threatened species, while pediments are essential because they are harboring higher species richness. These observed differences reflect how both components (hills and pediments), usually indiscriminate in rocky outcrops studies, reflects different importance for the biodiversity conservation.

Estimations of species richness suggest that the probabilities of recording a new amphibian species are scarce. Regarding reptiles, their representativeness was acceptable, although it was lower than that of amphibians. Aspects of the ecology and life habits of reptiles, especially snakes, which are usually not perceptible to visual encounters, could affect its detectability (Urbina-Cardona et al. 2008). Therefore, although the probabilities are low, it is possible to record other reptile species in the area, maybe, using different sampling techniques.

About 50% of the rare species from the rocky outcrops of PTC were snakes. This result is similar to that observed in inventories in RNAG (Zaracho et al. 2014) and RNI (Etchepare et al. 2013) and it seems to be a general pattern for reptile fauna inventories (Carvajal-Cogollo et al. 2007), probably due to the ecology and unpredictable life habits of this group of animals. We identified half of the threatened species as rare, in agreement with the idea of linking conservation problems with the ecological phenomenon of rarity (Carrascal & Palomino 2006). On the other hand, the relationship between the determinants of rarity and the real risk of the conservation of species can also vary greatly depending on distribution, abundance, ecological valence, geographic extension or different levels of human influence (Carrascal & Palomino 2006). Although *Homonota taragui* and *Ameivula* sp. are endemic taxa, their frequencies of occurrence were the highest. Endemic species can occur at higher levels than those of other species of more extensive distribution (Gaston 1994). Within amphibians, rarity may be related to the distributional limits in Corrientes province, in the case of *B. raniceps*, which is related to the eastern limit, and *S. similis*, to the southern limit, or the scarcity of suitable habitats for reproduction as for *R. fernandezae* and *P. albonotatus*. Rarity is a heterogeneous term that encompasses quite different phenomena so that its meaning has a broad sense. There is no single type of rarity and there is no single cause either. Rarity can be given by historical reasons, by the distribution/abundance relationship, by the body size, or by human intervention, among others (Méndez Iglesias 1998). Knowing the rarity of the species is an important first step to inquire about the biodiversity-ecosystem relationship of the rocky outcrops of the Paraje Tres Cerros. Identify and study the causal factors of the rarity will contribute to making decisions in future management and conservation plans of this natural area.

Although the surface size of the rocky outcrops of PTC is smaller than that of the other areas compared (except RPAT), this ecosystem had the highest IA of reptiles (Fig. 4, Table III). This pattern agrees with the idea that rocky outcrops have a high ecological value in relation to their size (Michael & Lindenmayer 2018), due to the habitat heterogeneity, microhabitat diversity and to the particular structural characteristics of the environmental conditions for this group of animals (Mares & Seine 2000, Fredericksen et al. 2003, Michael et al. 2008, Cajade et al. 2013a). Contrarily, the habitat less favorable for the reproduction of amphibians corresponds to moderate IA values.

Regarding the five exclusive species harbored by the rocky outcrops of PTC, *Homonota taragui* and *Ameivula* sp. are endemic species. This fact agrees with the diversity pattern described for rocky ecosystems around the world, which are recognized as speciation and diversification centers (Porembski et al. 1997, Michael et al. 2008), and sites with a singular conservation value, due to the endemic species role and its role as enricher of the regional biodiversity (Mares & Seine 2000, Michael & Lindenmayer 2018). On the other hand, the rocky outcrops of PTC constitute a unique area for endemic reptiles as compared with other natural areas of Corrientes province. Other exclusive species, despite not being present in the natural areas studied, can be recorded in other areas of Corrientes province, such as the case of *Amphisbaena trachura*, which is typically distributed in the Uruguay river basin (Ruiz-García et al. 2016).

The percentage of threatened species of the rocky outcrops of PTC was the highest. Furthermore, two out of the seven threatened species are endemic (*Homonota taragui* and *Ameivula* sp.). Nevertheless, despite their conservation status, they were the most frequent reptile species in this ecosystem. We suggest that the high frequency of *Homonota taragui* and *Ameivula* sp. responds to their endemicity in association with the singular rocky microhabitats that favor these species. Although the populations seemed to be relatively stable, they deserve attention because any perturbation or small environmental change could lead to the extinction of these microendemisms (Cajade et al. 2013a, b), as reflected by the assessment of *Homonota taragui* as Critically Endangered on the IUCN Red List (Arzamendia et al. 2016). Differences between SUMIN (this study) and IUCN categorizations could be due because the IUCN assessment gave high importance to the low number of localities and the small correspondent portion of suitable habitat where the species inhabit than to other biological and demographic aspects.

Since β_{cc} or complementarity depends on the supply of resources in each habitat, the biota changes according to their food and spatial requirements (Halffter & Moreno 2005). In this sense, the habitat heterogeneity mentioned above may explain the difference in species composition between the rocky outcrops of PTC and the other sites without rocky outcrops of Corrientes province. The percentages of β_{cc} above 50% indicate that the species composition in the areas studied was considerably different. On average partitioned analysis of the beta showed that both the replacement and the difference in species richness act on the βcc, indicating that they could be caused by environmental conditions, competition between species, historical events and the diversity of niches available (Leprieur et al. 2011, Legendre 2014). Although the areas compared have been well explored and show high complete inventories, differences may be influenced by different methods and sampling efforts.

The importance of rocky outcrops in biodiversity conservation is attributed to their microclimatic conditions, habitat heterogeneity and relative isolation. The attribution to be relatively unaltered habitats makes them true biodiversity refuges (Porembski & Barthlott 2000, Burke 2003, Speziale & Ezcurra 2014, Fitzsimons & Michael 2017). Regarding the isolated rocky outcrops of PTC, many studies pointed out their importance in the conservation of animal and plant biodiversity (Meregalli 1998, Ravenna 2003, 2009, Cajade et al. 2013a, b, Fandiño et al. 2017, Ojanguren-Affilastro et al. 2017, Nadal et al. 2018, P. Gervazoni, unpublished data). Our present study reveals that, in addition, these rocky ecosystems represent favorable habitats mainly for reptiles and secondarily for amphibians.

Due to the vital role of rocky outcrops in preserving the herptiles biodiversity, the protection of the isolated rocky outcrops of PTC should be a priority, and any anthropic action that modifies their structural complexity or affects their functioning should be prevented. The scarce surface that covers the rocky outcrops studied and the singular richness of their flora and fauna (Cajade et al. 2013a, b, Fandiño et al. 2017, this study) highlight the need for social commitment to conserve and protect these fragile ecosystems. The Nazareno and Chico hills, but not the Capará hill, have been included in the protection of the Reserva Natural Privada Paraje Tres Cerros since 2015. In 2016, Paraje Tres Cerros was recognized as an

AICOM (Spanish acronym for "Important Area for Bats Conservation") (A. Argoitia, unpublished data). In 2017, Fandiño et al. (2017) suggested that it should also be recognized as an AICA (Spanish acronym for "important area for birds conservation"). This study also shows the importance of the rocky outcrops of PTC for the conservation of reptiles and amphibians and will thus be a tool to promote the management of new certificates on nature conservation. To achieve this objective is necessary to continue investigating the nature of this particular ecosystem and to join efforts to ensure its protection. In this sense our study provides new interpretations about the importance of these ecosystems in the biodiversity of herpetofauna at the regional level and offers a reference point in the south of South America to broaden the knowledge of this type of ecosystems around the world.

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APPENDIX

Species and registration numbers of all individuals deposited in the Colección Herpetológica de la Universidad Nacional del Nordeste (UNNEC), Corrientes, Argentina:

AMPHIBIA

Bufonidae: *Rhinella diptycha*: UNNEC 13435; *Rhinella fernandezae*: UNNEC 13436; *Melanophryniscus atroluteus*: UNNEC 13437.

Hylidae: *Dendropsophus nanus*: UNNEC 13438; *Dendropsophus sanborni*: UNNEC 13053; *Boana pulchellus*: UNNEC 13439; *Boana raniceps*: UNNEC 13440; *Scinax nasicus*: UNNEC 13441; *Scinax fuscovarius*: UNNEC 13442; *Scinax squalirostris*: UNNEC 13443; *Scinax similis*: UNNEC 13444; *Ololygon berthae*: UNNEC 13445; *Lysapsus limellum*: UNNEC 13446.

Phyllomedusidae: *Pithecopus azureus*: UNNEC 13447.

Leptodactylidae: *Leptodactylus latinasus*: UNNEC 13448; *Leptodactylus latrans*: UNNEC 13449; *Leptodactylus chaquensis*: UNNEC 13450; *Leptodactylus gracilis*: UNNEC 13451; *Pseudopaludicola falcipes*: UNNEC 13452; *Physalaemus albonotatus*: UNNEC 13453; *Physalaemus riograndensis*: UNNEC 13454; **Odontophrynidae:** *Odontophrynus americanus*: UNNEC 13455.

Microhylidae: *Elachistocleis bicolor*: UNNEC 13456.

REPTILIA

Phyllodactylidae: *Homonota taragui*: UNNEC 11280.

Teiidae: *Ameivula sp.*: UNNEC 13457; *Teius oculatus*: UNNEC 13458; *Salvator merianae*: UNNEC 13459.

Gymnophtalmidae: *Cercosaura schreibersii*: UNNEC 13460.

Amphisbaenidae: *Amphisbaena kingii*: UNNEC 13461 *Amphisbaena trachura*: UNNEC 13462.

Diploglossidae: *Ophiodes aff. striatus*: UNNEC 13463.

Boidae: *Eunectes notaeus*: UNNEC 13464

Viperidae: *Bothrops alternatus*: UNNEC 13465.

Colubridae: *Mastigodryas bifossatus*: UNNEC 13466; *Tantilla melanocephala*: UNNEC 13467; *Atractus reticulatus*: UNNEC 13468; *Oxyrhopus rhombifer*: UNNEC 13469; *Helicops infrataeniatus*: UNNEC 13470; *Hydrodynastes gigas*: UNNEC 13471; *Erythrolamprus jaegeri*: UNNEC 13472; *Erythrolamprus poecilogyrus:* UNNEC 12703; *Erythrolamprus semiaureus*: UNNEC 13473; *Lygophis flavifrenatus*: UNNEC 13474; *Lygophis anomalus*: UNNEC 13002; *Sibynomorphus turgidus*: UNNEC 13475; *Phalotris reticulatus*: UNNEC 13476; *Phalotris lemniscatus*: UNNEC 13477; *Philodryas aestiva*: UNNEC 13478; *Philodryas patagoniensis*: UNNEC 13479; *Philodryas agassizii*: UNNEC 13480; *Taeniophallus occipitalis*: UNNEC 13481; *Thamnodynastes hypoconia*: UNNEC 13482; *Xenodon dorbignyi*: UNNEC 13483; *Xenodon merremii*: UNNEC 13484.

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Author contributions

JMP and RC conceptualized the study, analyzed and interpreted the results. AH, AC, MRI and FM contributed on fieldwork and data analysis. JMP and RC wrote the manuscript with the contribution of all co-authors.