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Artículo

RICHNESS, ENDEMISM AND CONSERVATION OF SIGMODONTINE RODENTS IN ARGENTINA

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ABSTRACT. Sigmodontine rodents, with 86 genera and ~430 living species, constitute one of the most successful radiations of Neotropical mammals. In this contribution, we studied the distributional ranges of 108 sigmodontine species in Argentina. Our objectives were (i) to establish geographical patterns of species richness and endemism, and (ii) to evaluate the regional conservation status of these taxa. We constructed a minimum convex polygon for each species, using information from literature and biological collections. Individual maps were superimposed on a map of Argentina divided into cells of 25 km on each side. For each cell, we calculated the species richness, which varied between 1 and 21 species, and its degree of endemism, which fluctuated between 0.001 and 3.28. There were 30 species of sigmodontine rodents distributed almost exclusively in Argentina, most of them restricted to forested areas (Southern Andean Yungas) or to arid and semiarid environments (High and Low Monte and Patagonian Steppe). Areas with high species richness and endemism scores corresponded grossly with the Southern Andean Yungas, the Humid Chaco plus the Paraná flooded savannas, the Alto Parana Atlantic forests plus the Araucaria moist forests, the High Monte and the ecotone between the Patagonian steppe and the Valdivian temperate forests. A reassessment of the conservation status of sigmodontine rodents distributed in Argentina retrieved 2 extinct species, 7 endangered, 7 vulnerable, 6 near threatened and 13 data deficient. These numbers suggest a much more serious situation than the expressed by previous evaluations, highlighting the urgent need to establish conservation measures for the protection of this group.

RESUMEN. Riqueza, endemismo y conservación de roedores sigmodontinos en Argentina. Los roedores sigmodontinos, con 86 géneros y ~430 especies vivientes, constituyen una de las radiaciones más exitosas de mamíferos neotropicales. En esta contribución, estudiamos los rangos de distribución de 108 especies de sigmodontinos en Argentina. Nuestros objetivos fueron (i) establecer patrones geográficos de riqueza de especies y endemismo y (ii) evaluar el estado de conservación regional de estos taxones. Construimos un polígono convexo mínimo para cada especie, utilizando información de la literatura y colecciones biológicas. Los mapas individuales fueron superpuestos en un mapa de Argentina dividido en celdas de 25 km de lado. Para cada celda, calculamos la riqueza de especies, que varió entre 1 y 21, y su grado de endemismo, que fluctuó entre 0.001 y 3.28. Hubo 30 especies de roedores sigmodontinos distribuidos casi exclusivamente en Argentina, la mayoría de ellos restringidos a áreas boscosas (Yungas andinas del sur) o a ambientes áridos y semiáridos (Monte alto y bajo y Estepa Patagónica). Las áreas con mayor riqueza de especies y valores más altos de endemismo se correspondieron groseramente con las Yungas andinas del sur, el Chaco húmedo más las Sabanas inundadas de Paraná, el Bosque Atlántico del Alto Paraná más los Bosques húmedos de araucaria, el Monte alto y el ecotono entre la Estepa Patagónica y los Bosques templados valdivianos. Una reevaluación del estado de conservación de los roedores sigmodontinos distribuidos en Argentina recuperó 2 especies extintas, 7 en peligro, 7 vulnerables, 6 casi amenazadas y 13 con datos deficientes. Estas cifras sugieren una situación mucho más grave que la

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expresada en evaluaciones anteriores, destacando la necesidad urgente de establecer medidas de conservación para la protección de este grupo.

Key words: Cricetidae, endangered species, extinction, Muroidea, Rodentia.

Palabras clave: Cricetidae, especie en peligro, extinción, Muroidea, Rodentia.

INTRODUCTION

During the last 500 years, almost 100 species of mammals became extinct, rodent species being more than a half of them (Turvey 2009). Only in South and Central America, including both continental and insular areas, ~32 species of rodents disappeared in the last five centuries (Turvey 2009, Teta et al. 2014). If we consider rodent extinctions across the Holocene (i.e., the last 10 000 years), the global number of lost species ascends to 115 (Turvey 2009). This scenario contradicts the generalized perception that rodents lack major conservation problems (Lacher et al. 2017).

Like other small mammals, rodents play a fundamental role in trophic chains acting as prey of other vertebrates (Jaksic 2002). Many rodent species occupy specialized ecological niches, contributing to energy and nutrient flow and providing important functions to the ecosystems, such as soil tilling and seed dispersal (Lacher et al. 2017). This situation contrasts with the lack of knowledge about this group, especially regarding the conservation status of their different members. A number of factors negatively influences over this situation, making it even more serious. On one hand, rodents are one of the most diverse and at the same time least known groups of Mammalia, with many species that are known only from the type specimen or series and sometimes from collections carried out more than 100 years ago (Amori et al. 2016). On the other hand, rodents are not charismatic species, attracting little attention from researchers and officials responsible for directing scientific resources and funding (Fleming & Bateman 2016).

Sigmodontine rodents, with 86 living genera and ca. 430 living species, constitute one of the most successful radiations of Neotropical mammals (Parada et al. 2015, Maestri et al. 2016). Species of this group are mostly distributed in South America and, to a lesser extent, in Middle and North America (D'Elía & Pardiñas 2015). Sigmodontine rodents occur from the humid rainforests of the Amazon to the extremely dry desert of Atacama (Maestri & Patterson 2016). Their diets are usually omnivorous, but there are species almost strictly herbivorous, insectivorous and fungivorous (Maestri et al. 2016). Despite their generalized morphology, sigmodontine rodents occupy from arboreal to cursorial, fossorial or semiaquatic niches (D'Elía & Pardiñas 2015).

At least 108 species of sigmodontine rodents have been recorded for Argentina, including representatives of nine tribes and some incertae sedis taxa (Patton et al. 2015, Teta et al. 2018). The tribes Akodontini and Oryzomyini were best represented in subtropical and temperate regions, both in forested and open environments. Abrotrichini and Phyllotini predominated towards high latitudes and Andean ranges. Phyllotini was also dominant in arid to semiarid open areas of western Argentina, where it reached its greatest diversity. Finally, Andinomyini and Euneomyini were distributed mostly in high mountain areas, Reithrodontini was widespread along open grassy areas and Thomasomyini and those taxa considered as incertae sedis occurred mostly in forested habitats (cf. Patton et al. 2015).

In this paper, two main issues were addressed. First, we evaluated geographical patterns of species richness and endemism of sigmodontine rodents in Argentina. Second, and based on the analysis of the available data, we proposed new conservation status for the species in this group at the regional level, demonstrating a more serious regional situation than previously reported.

MATERIALS AND METHODS

Argentina covers an area of almost 2.8 million km^2, including both continental and insular portions. This country is the second largest in the Neotropics and the eight largest in the world (Real et al. 2003). Although the usage of political divisions to address biogeographical issues is often criticized because patterns and processes responsible for biological diversity do not recognize artificial boundaries (such as the frontiers among countries), we decided to choose this approach because the application of conservation measures is usually conducted at regional or national administrative levels (Real et al. 2003). In addition, it is widely accepted that political limits shape human activities and are not always completely arbitrary; in fact, political boundaries sometimes coincide with natural barriers (e.g., the Andean Cordillera to the west of Argentina), being suitable to detect some natural phenomena (Real et al. 2003). The scheme of ecoregions used in this work follows Olson et al. (2001).

Distributional data for 108 species of sigmodontine rodents inhabiting Argentina were taken from Patton et al. (2015) and updated when necessary (Jayat et al. 2016, Pardiñas et al. 2016a, Pardiñas et al. 2016b, Teta et al. 2017, Teta and D'Elía 2017). Taxonomy follows Teta et al. (2018). Point data for marginal records of each species were imported into Geographic Information System (GIS) and transformed to minimum convex polygons (= extent of the occurrence). Distributional ranges were calculated for each taxa, except for those with only 1 locality record (IUCN Species Survival Commission 2012). The polygons for those species exceeding the geographic limits of Argentina were clipped and the range size in km^2 (area) for each species was calculated. Complete lists of localities were compiled only for those species with an extent of occurrence less than 20 000 km^2, as this value, combined with the number of localities, demography and threats, is used as a cut-off point by the UICN to separate between threatened and not-threatened categories.

For calculating species richness (S), a grid with square cells of 25 km^2 was created and the number of species in each cell was counted. Data projections and calculations were carried out using the software ArcGIS Desktop 10.5.1 (ESRI 2017) and the projected coordinate system WGS84/UTM zone 19S (EPSG: 32719).

Endemism was calculated both as categorical and continuous variables. First, we considered a taxon as endemic to Argentina if it occurs mostly (>98% of its distributional range) or exclusively within the limits of the country. The rationale behind this procedure is that the conservation status of these species would depend almost exclusively on the policies adopted by the Argentinean legislative bodies at national or regional levels. Secondarily, we calculated endemism as a continuous variable, following the equation of Kryštufek and Griffiths (2002, see also Kryštufek et al. 2009): $Ej = \Sigma 1/Ai$, for all i included in Sj, where Ai is the number of cells for every species with $i = 1$ to n (the maximum number of species). In each geographical cell j is the set of species Sj found within it. The sum of the weights of 1/Ai for every species found in set Sj produced an overall measure of endemism Ej. The contribution made by a species is constant for each cell (Nott & Pimm 1997, Kryštufek & Griffiths 2002). Species with range distributions above 106 km^2 were excluded from the analysis, since their individual contribution to a cell would be $< 10^{-3}$.

Areas with high levels of biodiversity were considered as "hotspots," defining them as those cells with high species richness or high endemism scores, the cut-off point being the upper quartile (i.e. the top 25% squares; for a similar procedure, see Kryštufek & Griffiths 2002). Expressed in this way, this is the inverse of the definition of rarity proposed by Gaston (1994). Those cells with high species richness plus high endemism scores were considered as "top hotspots." The statistical significance of "top hotspots" was tested using the Getis-Ord Gi* tool of ArcGIS (Getis & Ord 1992). This statistic allows the identification of "hotspots", higher or lower in magnitude than one might expect to find by chance; in addition, this method compares the value for a given observation with locations in the neighborhood, thus providing a more explicit consideration of space (Nelson & Boots 2008).

Global conservation status were taken from the IUCN Red List (2011). New species assessments were based on the categories and guidelines defined by the IUCN for regional level (IUCN Species Survival Commission 2012). This methodology considers the number of known localities in which a certain species was documented and the extent of its distribution, plus additional information (if available) about demographic parameters (see IUCN Species Survival Commission 2012). For some species, preliminary categorizations were changed as long as there was a possibility of a "rescue effect" from populations outside the region (see IUCN Species Survival Commission 2012). With few exceptions, species based on historical records or documented for only one or two localities (e.g., *Andalgalomys pearsoni*, *Necromys amoenus*), with dubious taxonomic status (e.g., *Graomys edithae*), or both (e.g., *Brucepattersonius guarani*, *B. misionensis*, *B. paradisus*) were considered as Data Deficient.

RESULTS

Geographical range sizes for 108 sigmodontine species varied from 67.18 km^2 to 1 439 529.18 km^2, representing from 0.0024% to 51.77% of the total surface of Argentina (**Table 1**). Only 16 species have distributional ranges that covered more than 20% of the total area of the country, while the other 92 species occupied less than 19% each, with 52 species (this is 48.14% of total number of species) occurring in an area smaller than 1% (**Table 1**). Species with a range size less than 5501.58 km^2 (= upper limit for the lower quartile of the species ranges annotated in **Table 1**) were considered rare (N = 27), according to the definition of Gaston (1994). Species richness varied between 1 and 21 species per grid cell (mean = 8.14). The highest values (i.e., S ≥ 14) mostly corresponded to five main areas: 1) Southern Andean Yungas, 2) Humid Chaco plus Paraná flooded savannas, 3) Alto Parana Atlantic forests plus Araucaria moist forests, 4) High Monte, and 5) the ecotone between the Patagonian steppe and the Valdivian temperate forests (**Fig. 1**).

There are 30 species almost exclusively distributed in Argentina, 13 belonging to Phyllotini, 13 to Akodontini, 2 to Abrotrichini and 2 to Oryzomyini. Most species in this category were distributed towards the western portion of the country (most cells ≥ 7 endemic species), both in forested areas (e.g., Southern Yungas) and open, arid to semiarid, areas (e.g., High and Low Monte, Patagonian steppe) (**Fig. 2**). The distributional range size of endemic species varied between 67.18 and 894 733.81 km^2, with almost the half of them being distributed in less than 1000 km^2 (**Table 1**).

Endemism scores varied between 0.001 and 3.28 (mean = 0.02). Highest values for this variable mostly correspond to cells with high species richness (i.e, Southern Andean Yungas, Humid Chaco, Alto Parana Atlantic forests and High Monte) and those characterized by the presence of endemic species (e.g., Delta del Paraná, southeastern Mendoza, southwestern Buenos Aires) (**Fig. 3**). The Spearman correlation coefficient between species richness and endemism scores was 0.71 ($p < 0.0001$)

"Hotspots" were defined as those cells with species richness ≥ 10 or with an endemism score ≥ 0.018, retrieving 1257 cells (25.8% of the total surface of Argentina); of these, 730 (14.9% of the total surface of Argentina) are considered as "top hotspot", since they outperformed in both parameters simultaneously (**Fig. 4**). Statistical significance of "top hotspots" is depicted on **Supplement 1**.

The reassessment of the conservation status of Argentinean sigmodontine rodents retrieved 2 Extinct species (1 Akodontini, 1 Oryzomyini), 7 Endangered (3 Akodontini, 4 Phyllotini), 7 Vulnerable (2 Akodontini, 1 Oryzomyini, 1 Phyllotini, 3 incertae sedis), 6 Near Threatened (4 Akodontini, 2 Phyllotini), 73 Least Concern and 13 Data Deficient (see **Table 1**; **Fig. 5**). Endangered species were mostly distributed in forested, arid to semiarid, and grassy environments (**Fig. 6**). Justification for each individual case is provided on **Table 2**.

DISCUSSION

The study and comprehension of geographical patterns of species richness and endemism is crucial for the conservation of biodiversity (e.g., Ceballos et al. 2005). Understanding how biodiversity is changing and responding to global change allows us to update, when necessary, the conservation status of species, in order to contribute preserving their populations (e.g., Lacher et al. 2017; this work). In this work, we analyzed the geographic distribution, species richness, endemism, and conservation status of 108 sigmodontine rodents that inhabit Argentina. The main results of our contribution are: (i) species richness, endemism scores and "hotspots" were moderately correlated and correspond to five main areas (see below); (ii) almost half of the studied species occupies, each, less than 1% of the country surface; (iii) the re-evaluation of conservation status

Table 1

Sigmodontine rodents from Argentina: species list (arranged by range size), distributional range (occupied area in Argentina), global status according IUCN Red List (2011), regional status in Argentina according to Teta & Pardiñas (2012) and updated status (this work).

Species	Tribe	Endemic	Range size (km²)	Status IUCN	Teta & Pardiñas 2012	This work
Brucepattersonius guarani	Akodontini	yes	-	DD	DD	DD
Brucepattersonius misionensis	Akodontini	yes	-	DD	DD	DD
Brucepattersonius paradisus	Akodontini	yes	-	DD	DD	DD
Tapecomys sp.	Phyllotini	yes	-	not evaluated	not evaluated	DD
Phyllotis anitae	Phyllotini	yes	-	DD	DD	EN B1ab(iii)
Necromys lilloi	Akodontini	yes	-	not evaluated	not evaluated	EN B1ab(iii)
Graomys edithae	Phyllotini	yes	-	DD	DD	DD
Holochilus lagigliai	Oryzomyini	yes	-	not evaluated	not evaluated	EX
Andalgalomys pearsoni	Phyllotini	no	-	LC	not evaluated	DD
Gyldenstolpia fronto	Akodontini	yes	-	EN B1ab(iii)	EX	EX
Phyllotis bonaeriensis	Phyllotini	yes	67.18	NT	not evaluated	NT
Akodon philipmyersi	Akodontini	yes	81.40	DD	DD	EN B1ab(iii)
Phyllotis alisosiensis	Phyllotini	yes	112.11	not evaluated	not evaluated	EN B1ab(iii)
Necromys amoenus	Akodontini	no	158.09	LC	DD	DD
Akodon sylvanus	Akodontini	yes	212.94	LC	LC	NT
Phyllotis caprinus	Phyllotini	no	347.95	LC	DD	DD
Bibimys torresi	Akodontini	yes	800.10	NT	VU B2ab(ii, iii)	EN B1ab(iii)
Abrothrix manni	Abrotrichini	no	1 141.09	not evaluated	not evaluated	DD
Abrawayaomys ruschi	Incertae sedis	no	1 957.50	LC	EN B1a,b(i, iii)	VU B1ab(iii)
Phyllotis nogalaris	Phyllotini	yes	2 734.37	not evaluated	not evaluated	EN B1ab(iii)
Delomys dorsalis	Incertae sedis	no	2 848.81	LC	DD	VU B1ab(iii)
Andalgalomys olrogi	Phyllotini	yes	3 329.84	LC	VU B1a,b(iii)	EN B1ab(iii)
Oxymycterus wayku	Akodontini	yes	3 523.57	not evaluated	DD	EN B1ab(iii)

(Table 1 cont.)

Species	Tribe	Endemic	Range size (km²)	Status IUCN	Teta & Pardiñas 2012	This work
Castoria angustidens	Akodontini	no	4 910.30	LC	DD	VU B1ab(iii)
Oxymycterus paramensis	Akodontini	no	5 441.05	LC	LC	LC
Tapecomys primus	Phyllotini	no	5 501.58	LC	DD	VU B1ab(iii)
Akodon polopi	Akodontini	yes	5 516.52	not evaluated	LC	LC
Calomys tener	Phyllotini	no	8 453.30	LC	not evaluated	DD
Abrothrix illutea	Abrotrichini	yes	8 987.47	LC	LC	LC
Deltamys kempi	Akodontini	no	9 203.65	LC	LC	NT
Necromys obscurus	Akodontini	no	9 452.50	NT	LC	NT
Euryoryzomys russatus	Oryzomyini	no	10 218.94	LC	LC	LC
Akodon budini	Akodontini	no	10 485.62	LC	DD	LC
Bibimys chacoensis	Akodontini	no	12 721.12	LC	NT	NT
Akodon boliviensis	Akodontini	no	13 424.05	LC	DD	LC
Abrothrix jelskii	Abrotrichini	no	16 197.29	LC	DD	DD
Oxymycterus quaestor	Akodontini	no	16 371.96	LC	LC	LC
Eligmodontia bolsonensis	Phyllotini	yes	16 473.83	not evaluated	DD	NT
Blarinomys breviceps	Akodontini	no	16 609.83	LC	DD	DD
Euryoryzomys legatus	Oryzomyini	no	16 629.02	LC	LC	LC
Nectomys squamipes	Oryzomyini	no	18 357.79	LC	LC	LC
Juliomys pictipes	Wiedomyini	no	18 774.58	LC	EN B1a,b(i,iii)	VU B1ab(iii)
Oecomys franciscorum	Oryzomyini	no	19 395.39	not evaluated	DD	VU B1ab(iii)
Rhipidomys austrinus	Thomasomyini	no	19 913.79	LC	DD	LC
Abrothrix xanthorhina	Abrotrichini	no	20 099.79	not evaluated	not evaluated	LC
Abrothrix lanosa	Abrotrichini	no	20 358.87	LC	LC	LC
Brucepattersonius iheringi	Akodontini	no	20 529 27	LC	not evaluated	LC

(Table 1 cont.)

Species	Tribe	Endemic	Range size (km²)	Status IUCN	Teta & Pardiñas 2012	This work
Akodon fumeus	Akodontini	no	22 772.76	LC	DD	LC
Auliscomys sublimis	Phyllotini	no	23 826.38	LC	DD	LC
Akodon paranaensis	Akodontini	no	24 761.20	LC	DD	DD
Thaptomys nigrita	Akodontini	no	26 388.69	LC	DD	LC
Euneomys mordax	Euneomyini	no	26 663.55	LC	VU B1a,b(iii)	LC
Andalgalomys roigi	Phyllotini	yes	33 603.11	not evaluated	not evaluated	LC
Oligoryzomys fornesi	Oryzomyini	no	34 957.81	LC	LC	LC
Irenomys tarsalis	Euneomyini	no	42 532.97	LC	LC	LC
Reithrodon typicus	Reithrodontini	no	50 589.27	LC	LC	LC
Calomys boliviae	Phyllotini	no	52 422.57	LC	LC	LC
Akodon caenosus	Akodontini	no	56 916.52	not evaluated	LC	LC
Calomys venustus	Phyllotini	yes	57 609.23	LC	LC	LC
Graomys domorum	Phyllotini	no	59 847.53	LC	LC	LC
Oligoryzomys brendae	Oryzomyini	yes	61 441.52	LC	LC	LC
Geoxus michaelseni	Abrotrichini	no	62 418.34	not evaluated	not evaluated	LC
Geoxus valdivianus	Abrotrichini	no	63 110.28	LC	LC	LC
Sooretamys angouya	Oryzomyini	no	64 798.17	LC	LC	LC
Phyllotis tucumanus	Phyllotini	no	66 158.90	not evaluated	not evaluated	LC
Calomys lepidus	Phyllotini	no	70 648.73	LC	LC	LC
Akodon albiventer	Akodontini	no	72 092.69	LC	LC	LC
Akodon montensis	Akodontini	no	74 721.24	LC	LC	LC
Salinomys delicatus	Phyllotini	yes	78 421.67	DD	VU B2ab(ii, iii)	LC
Andinomys edax	Andinomyini	no	87 053.83	LC	LC	LC
Necromys lactens	Akodontini	no	91 900.07	LC	LC	LC

(Table 1 cont.)

Species	Tribe	Endemic	Range size (km²)	Status IUCN	Teta & Pardiñas 2012	This work
Eligmodontia puerulus	Phyllotini	no	101 932.40	LC	LC	LC
Pseudoryzomys simplex	Oryzomyini	no	106 685.38	LC	LC	LC
Akodon simulator	Akodontini	no	110 088.62	LC	LC	LC
Necromys lenguarum	Akodontini	no	140 818.18	LC	not evaluated	LC
Calomys callidus	Phyllotini	no	141 586.64	LC	LC	LC
Neotomys ebriosus	Euneomyini	no	142 100.32	LC	LC	LC
Eligmodontia moreni	Phyllotini	yes	158 987.40	LC	LC	LC
Akodon spegazzinii	Akodontini	yes	168 969.86	LC	LC	LC
Notiomys edwardsii	Abrotrichini	yes	201 333.83	LC	LC	LC
Scapteromys aquaticus	Akodontini	no	225 696.80	LC	LC	LC
Oligoryzomys nigripes	Oryzomyini	no	230 174.17	LC	LC	LC
Paynomys macronyx	Abrotrichini	no	245 209.03	LC	LC	LC
Akodon toba	Akodontini	no	251 459.55	LC	LC	LC
Loxodontomys micropus	Phyllotini	no	281 546.04	LC	LC	LC
Abrothrix andina	Abrotrichini	no	300 354.40	LC	LC	LC
Oligoryzomys chacoensis	Oryzomyini	no	313 887.41	LC	LC	LC
Calomys callosus	Phyllotini	no	326 653.47	LC	LC	LC
Oxymycterus rufus	Akodontini	no	336 224.09	LC	LC	LC
Abrothrix hirta	Abrotrichini	no	373 948.34	not evaluated	not evaluated	LC
Euneomys chinchilloides	Euneomyini	no	454 297.68	LC	LC	LC
Eligmodontia morgani	Phyllotini	no	527 192.55	LC	LC	LC
Abrothrix olivacea	Abrotrichini	no	576 893.63	LC	LC	LC
Eligmodontia typus	Phyllotini	no	600 433.26	LC	LC	LC
Akodon iniscatus	Akodontini	yes	624 727.16	LC	LC	LC

(Table 1 cont.)

Species	**Tribe**	**Endemic**	**Range size (km²)**	**Status IUCN**	**Teta & Pardiñas 2012**	**This work**
Holochilus vulpinus	Oryzomyini	no	643 956.65	not evaluated	not evaluated	LC
Holochilus chacarius	Oryzomyini	no	712 486.17	LC	LC	LC
Graomys chacoensis	Phyllotini	no	721 469.11	LC	LC	LC
Oligoryzomys longicaudatus	Oryzomyini	no	783 702.62	LC	LC	LC
Graomys griseoflavus	Phyllotini	yes	784 211.49	LC	LC	LC
Phyllotis xanthopygus	Phyllotini	no	844 599.16	LC	LC	LC
Akodon azarae	Akodontini	no	886 293.24	LC	LC	LC
Akodon dolores	Akodontini	yes	894 733.81	LC	LC	LC
Reithrodon auritus	Reithrodontini	no	1 090 186.07	LC	LC	LC
Calomys laucha	Phyllotini	no	1 144 263.14	LC	LC	LC
Necromys lasiurus	Akodontini	no	1 211 173.29	LC	LC	LC
Calomys musculinus	Phyllotini	no	1 228 573.07	LC	LC	LC
Oligoryzomys flavescens	Oryzomyini	no	1 439 529.18	LC	LC	LC
Extinct				-	1	2
Endangered				1	2	7
Vulnerable				-	4	7
Near treatened				2	1	6
Least concern				80	60	73
Data deficient				7	24	13

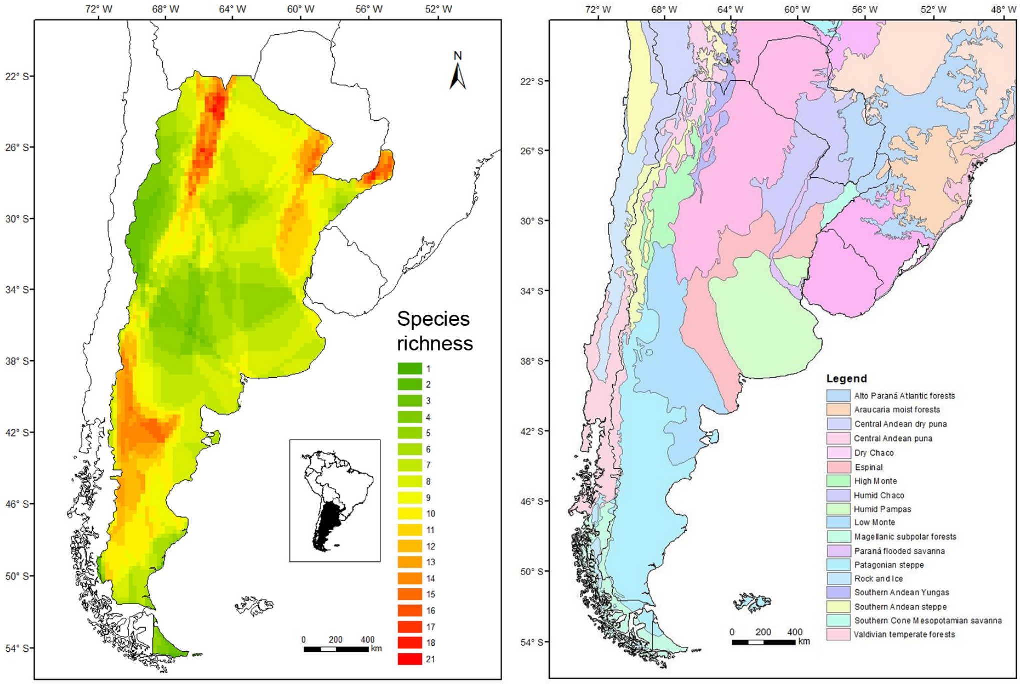

Fig. 1. Map of Argentina depicting species richness of sigmodontine rodents (left) and ecoregions according to Olson et al. 2001 (right).

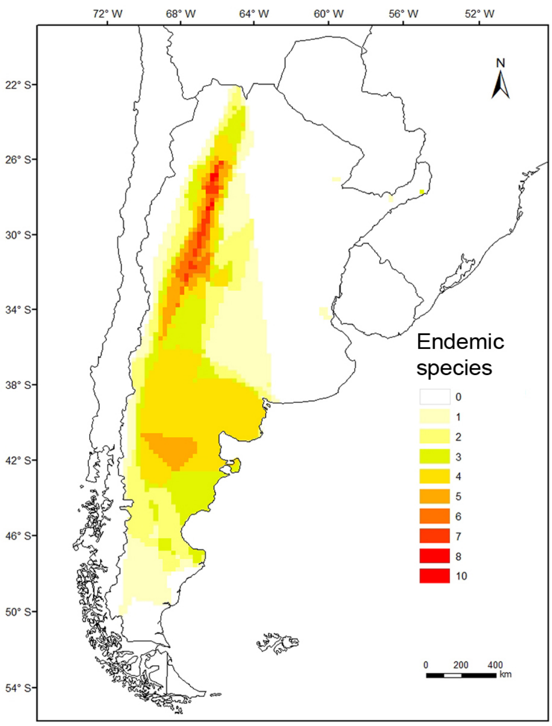

Fig. 2. Map of Argentina depicting the superimposed distributions of endemic species of sigmodontine rodents.

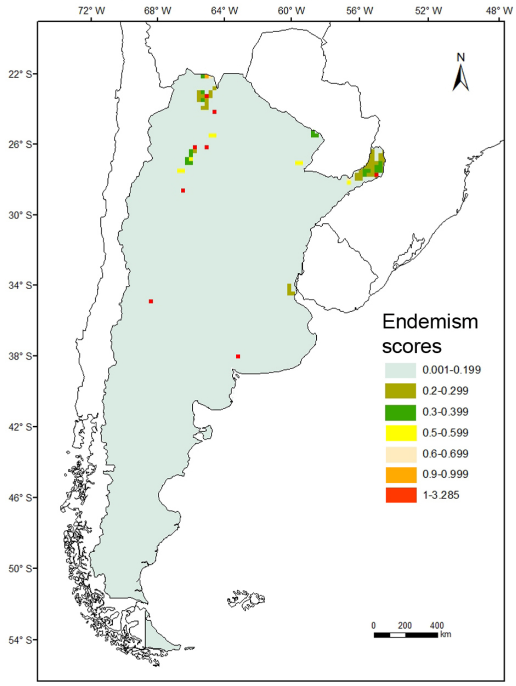

Fig. 3. Map of Argentina depicting endemism scores for sigmodontine rodents.

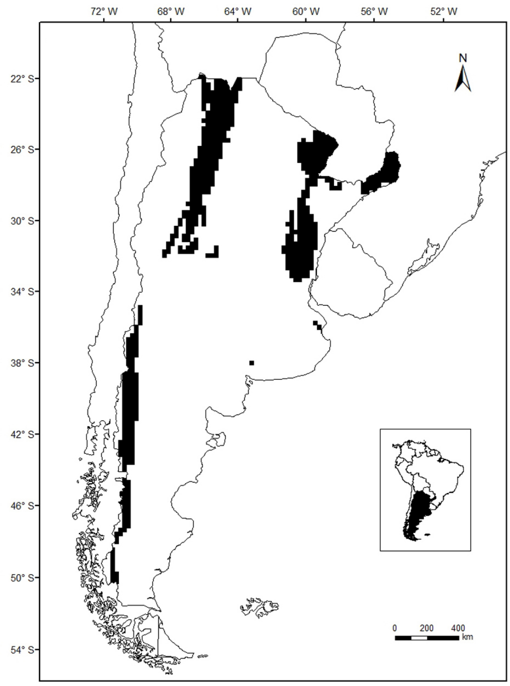

Fig. 4. Map of Argentina depicting "top hotspots" (= black cells) for sigmodontine rodents.

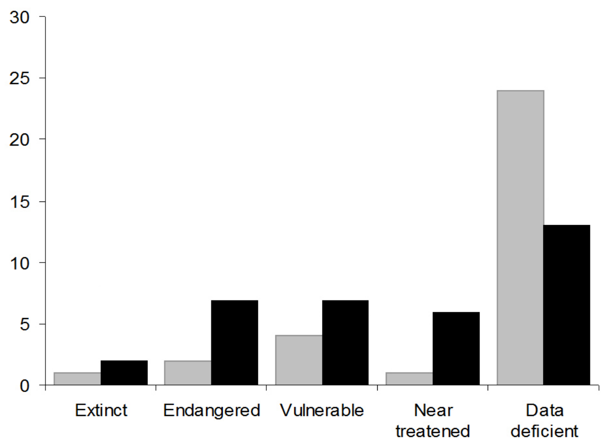

Fig. 5.Histograms of species conservation status for sigmodontine rodents as defined by Teta and Pardiñas (2012; gray bars) and this work (black bars).

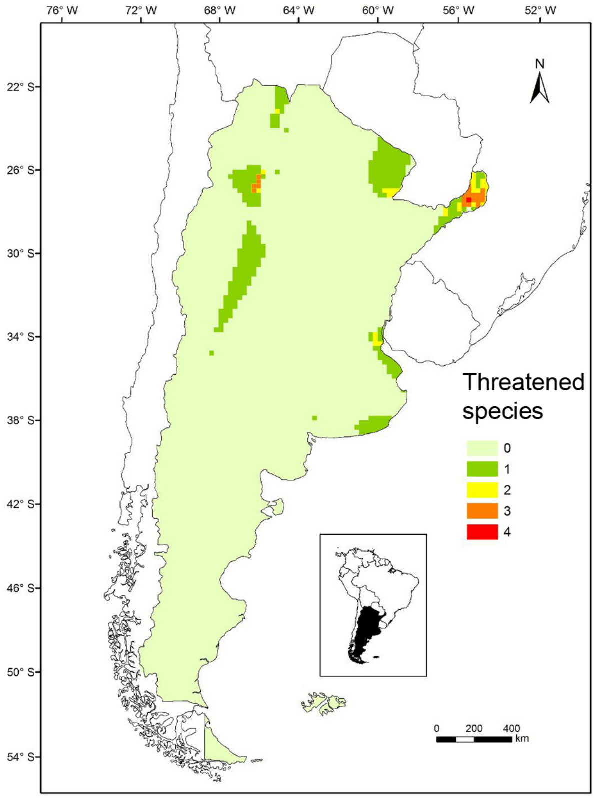

Fig. 6. Map of Argentina showing the superimposed distribution of threatened species of sigmodontine rodents.

at the regional level revealed a more critical situation than the one reported in a previous assessment (Teta & Pardiñas 2012).

High values of species richness and endemism scores coincided mostly in five main areas: 1) Southern Andean Yungas, 2) Humid Chaco plus Paraná flooded savannas, 3) Alto Parana Atlantic forests plus Araucaria moist forests, 4) High Monte, and 5) the ecotone between the Patagonian steppe and the Valdivian temperate forests. Most of those areas are adjacent to hilly or mountain chains (i.e., the Southern Andean Yungas, the High Monte and the ecotone between the Patagonian steppe and the Valdivian temperate forest are close to the Andes; the Alto Parana Atlantic forests and Araucaria moist forests are influenced by the relatively high elevations of the Serra do Mar and adjacent high plateaus of eastern Brazil), that offers high environmental heterogeneity (Amori et al. 2012). Mountain ranges, by establishing barriers to dispersal, creating vertical succession of habitats, and isolating populations, potentially lead speciation (mostly by allopatry) and contribute to generate high species richness and turnover (Parada et al. 2015, Maestri & Patterson 2016). In fact, species richness for sigmodontine rodents is strongly affected by elevation, which in South America is mostly dominated longitudinally by the Andes (Maestri & Patterson 2016). In accordance with our results, most of these same areas are recognized as diverse and distinctive centers of mammalian endemism, such as the Brazilian Atlantic forest or the Monte desert (cf. Mares 1992, Amori et al. 2012, Maestri & Patterson 2016).

Statistically significant "top hotspots" were broadly coincident with the Southern Andean Yungas and the Alto Parana Atlantic forests, highlighting the importance of forested environments as areas with high species richness and unique taxa (Amori et al. 2012). Further analyses, incorporating phylogenetic and functional diversity as additional variables, are much needed in order to determine "hotspots" with more accuracy (Mazel et al. 2018).

Understanding diversity implies to consider not only species richness or endemism but also rarity (Halffter 1994). Rare species are those that occur in a small distributional range or with low abundances through large areas (Gaston 1994, Halffter 1994). Species with small geographic ranges are expected to be more vulnerable to habitat deterioration and other localized anthropogenic disturbances. Our results showed that almost half of the sigmodontine rodents distributed in Argentina (N = 52) occupies, each, less than 1% of the total surface of the country; among these, 27 (including 18 endemic) could be considered rare following the definition of Gaston (rarity being defined as the inverse of range size, i.e. the converse

Table 2

Justification of the threatened status of species of sigmodontine rodents from Argentina. An asterisk denotes a change in the conservation status based on the rescue effect from neighbor countries (see IUCN Species Survival Commission 2012). Use of term "location" follows the definition provided by the IUCN Species Survival Commission (2012).

Species	Status	Range size	Justification
Abrawayaomys ruschi	VU B1ab(iii)*	1957.50	Extent of occurrence < 5000 km², all individuals in < 5 locations; the extent and quality of its habitat is declining.
Akodon philipmyersi	EN B1ab(iii)	81.40	Extent of occurrence < 5000 km², all individuals in < 5 locations; the extent and quality of its habitat is declining.
Andalgalomys olrogi	EN B1ab(iii)	3329.84	Extent of occurrence < 5000 km², all individuals in < 5 locations; the extent and quality of its habitat is declining.
Necromys lilloi	EN B1ab(iii)	-	Extent of occurrence < 5000 km², all individuals in < 5 locations; the extent and quality of its habitat is declining.
Phyllotis anitae	EN B1ab(iii)	-	Extent of occurrence < 5000 km², all individuals in < 5 locations; the extent and quality of its habitat is declining.
Phyllotis alisosiensis	EN B1ab(iii)	112.11	Extent of occurrence < 5000 km², all individuals in < 5 locations; the extent and quality of its habitat is declining.
Phyllotis nogalaris	EN B1ab(iii)	2734.37	Extent of occurrence < 5000 km², all individuals in < 5 locations; the extent and quality of its habitat is declining.
Bibimys torresi	EN B1ab(iii)	800.10	Extent of occurrence < 50000 km², all individuals in < 5 locations; the extent and quality of its habitat is declining.
Castoria angustidens	VU B1ab(iii)*	4910.30	Extent of occurrence < 5000 km², all individuals in < 5 locations; the extent and quality of its habitat is declining.
Delomys dorsalis	VU B1ab(iii)*	2848.81	Extent of occurrence < 5000 km², all individuals in < 5 locations; the extent and quality of its habitat is declining.
Juliomys pictipes	VU B1ab(iii)	18774.58	Extent of occurrence < 20 000 km², all individuals in < 10 locations; the extent and quality of its habitat is declining.

(Table 2 cont.)

Species	Status	Range size	Justification
Oecomys franciscorum	VU B1ab(iii)	19395.39	Extent of occurrence < 20 000 km², all individuals in < 10 locations; the extent and quality of its habitat is declining.
Oxymicterus wayku	VU B1ab(iii)	3,523.57	Extent of occurrence < 5000 km², all individuals in < 10 locations; the extent and quality of its habitat is declining.
Tapecomys primus	VU B1ab(iii)*	5501.58	Extent of occurrence < 20 000 km², all individuals in < 10 locations; the extent and quality of its habitat is declining.
Akodon sylvanus	NT	212.94	Although common in its small range, its extent of occurrence is < 5,000 km², and the extent and quality of its habitat is declining.
Bibimys chacoensis	NT	12721.12	Rare in its small range, its extent of occurrence is < 20,000 km², and the extent and quality of its habitat is declining.
Deltamys kempi	NT	9203.65	Rare in its small range, its extent of occurrence is < 20,000 km², and the extent and quality of its habitat is declining.
Eligmodontia bolsonensis	NT	16473.83	Although apparently common in its small range, its extent of occurrence is < 20,000 km², and the extent and quality of its habitat is declining.
Necromys obscurus	NT	9452.50	Although common in its small range, its extent of occurrence is < 20,000 km², and the extent and quality of its habitat is declining.
Phyllotis bonaeriensis	NT	67.18	Although common in its small range, its extent of occurrence is < 5,000 km², and the extent and quality of its habitat is declining. The only known population is included within a protected area.

of widespread). This situation is not surprising, because prevalence of rarity is a common phenomenon among other taxonomic groups in different geographical regions (Gaston 1994). In this study, species with restricted distributions occur mostly in the Southern Andean Yungas, the Alto Parana Atlantic forests plus Araucaria moist forests, and the Monte desert. Most species in the Southern Andean Yungas and the Monte desert are, according to current knowledge, truly restricted (**Table 1**); while most of those of the Alto Parana Atlantic forests plus Araucaria moist forests have reduced distributions in Argentina (due to the small range occupied by these forests in this country), although most of them are relatively widespread along the forested portions of eastern Paraguay and southeastern Brazil (cf. Patton et al. 2015).

The reassessment of the conservation status of Argentinean sigmodontine rodents showed a situation more critical and severe than currently envisioned. Our findings differ from the evaluation carried out by Teta & Pardiñas (2012) who reported 1 Extinct species (1 Akodontini), 2 Endangered (2 incertae sedis), 4 Vulnerable (1 Akodontini, 1 Euneomyini, 2 Phyllotini) and 1 Near Threatened (1 Akodontini). Despite some methodological issues resulting in such different figures, our results suggest a more worrying regional situation than that formerly reported. Regarding this point, it is important to note that all changes recorded since Teta & Pardiñas (2012) are non-genuine (i.e., those resulting—for example—from improved knowledge, taxonomic changes, or correction of earlier errors; see IUCN Species Survival Commission 2012), because of new available information or mistakes in the interpretation of some guidelines (e.g., Teta & Pardiñas [2012] do not consider the “rescue effect” from populations in neighbor countries or misunderstood the concept of locality according to the IUCN). We found that threatened species inhabit mostly forested environments, but also open, arid, semiarid to temperate, steppes and grasslands. Among those species that we considered as rare, there are 2 listed as Extinct, 7 Endangered and 3 Vulnerable (**Table 1**). Extinct species include the swamp rat *Gyldenstolpia fronto* (last seen in Brazil in the decade of 1990; the only known Argentinian specimen was secured in 1886 [Pardiñas et al. 2008, Bezerra 2011]) and the marsh rat *Holochilus lagigliai* (last seen in the decade of 1950 [Pardiñas et al. 2013]). Amori et al. (2012), from a continental perspective, reported no more than one threatened species per region across Argentina. Here, we documented a much different situation, with up to 3-4 threatened species in some parts of the High Monte and the Alto Parana Atlantic forests plus the Araucaria moist forests. These results highlight the need of regional assessments, especially when this type of information constitutes the base for future research or is used to taking regional conservation measures (see IUCN Species Survival Commission 2012).

Most threatened species shared some features that influence its conservation status, such as small distributional ranges, low abundances or a reduced number of locality records (**Table 2**). In most cases, these species occur in habitats where both their extension and quality are declining, such as the Alto Parana Atlantic forests, the Araucaria moist forests (e.g., *Castoria angustidens*, *Delomys dorsalis*, *Juliomys pictipes*) or the grasslands of Humid Pampas in central-eastern Argentina (e.g., *Deltamys kempi*, *Necromys obscurus*). The situation of the leaf-eared mice of the genus *Phyllotis* is outstanding, since at least 4 species of this taxon are considered under some threatened category. Species of *Phyllotis* are mostly restricted to rocky outcrops and high grassy areas, having, in some cases, extremely restricted ranges (Steppan & Ramírez 2015) in threatened environments (e.g., Southern Andean Yungas).

Our work has two potential sources of bias, one primarily related to taxonomic issues and the other linked to artifacts in species mapping (Kryštufek & Griffiths 2002, Isaac et al. 2004). For example, *Andalgalomys olrogi* is here categorized as endangered; however, this rodent was included by some researchers (e.g., Diaz et al. 2006) into the synonymy of *A. roigi*, a species categorized as of least concern. For the genus *Brucepattersonius*, there is at least three species with very restricted distributional areas (i.e., *Brucepattersonius guarani*, *B. misionensis*, *B. paradisus*), which were categorized as Data

Deficient due to their dubious taxonomic status and potential conspecificity (cf. Lanzone et al. 2018). Another example is the case of *Phyllotis tucumanus* from northwestern Argentina, whose taxonomic splitting would increase the endemism scores in an area already recognized as a "hotspot" and also reduce the average range sizes for the different species in this genus (see Jayat et al. 2016). Contrarily, the opposite effect would occur if *P. alisosiensisis* is included into the synonymy of *P. anitae*, as is suggested by the available morphological and molecular evidence (see Jayat et al. 2016). Regarding the species distribution datasets, our approach ignores that real ranges of species are better represented as mosaics than as continuous polygons in a map, which do not always represent the real geographic distribution of the species. Fortunately, it is well documented that broad biogeographic patterns are not sensitive to grid square size (see Schall & Pianka 1978, Di Marco et al. 2013).

The fragmentation of habitats and the loss of biodiversity are in constant advance and it seems to become even worse in coming decades. Human activities are the main cause of habitat loss, fragmentation and species extinction, but climate change is projected to be equally or even more important in the near future (Hoffman et al. 2010, Pereira et al. 2010, Dawson et al. 2011). Global biodiversity is currently under a huge pressure of change and threat (Ceballos et al. 2005). Recognizing and understanding this problem is crucial for carrying out plans for managing and protecting the species that more need it (Ceballos et al. 2005). For example, protected areas such as National Parks are scattered through Argentina, covering ca. 13% of its total surface. This protection is unevenly distributed, being mostly coincident with areas of natural attractions or impressive landscapes (e.g., Alto Parana Atlantic forests, Valdivian temperate forests). From our data, it is clear that additional protected areas are strongly needed in some distinctive ecoregions, such as the High Monte that supports numerous endemic species. In many countries, and more especially in developing ones, funds designated to conservation are limited, even when the need for constant updates on the knowledge of species is crucial for their conservation (Ceballos et al. 2005). The situation of the order Rodentia is paradigmatic, because historical records suggest that the species in this group are among the most vulnerable mammals to extinction due to human activities (Turvey 2009). Simultaneously, this group includes some of the least known mammal species of the world. Funding of specific conservation projects for rodents is a first step to maintaining the exceptional diversity of this order on our planet.

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ONLINE SUPPLEMENTARY MATERIAL

Supplement 1

https://www.sarem.org.ar/wp-content/uploads/2019/08/SAREM_MastNeotrop_26-1_Formoso-sup1.doc

Fig. S1. Maps of Argentina depicting the statistical significance of "top hotspots" for sigmodontine rodents (left, species richness; right, endemism scores).