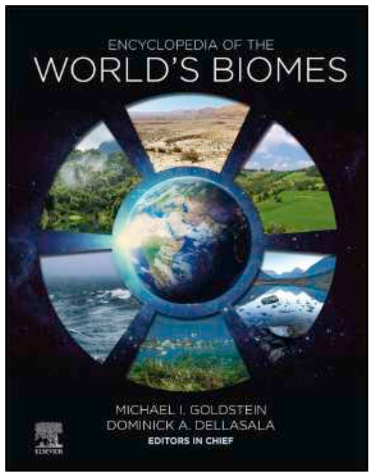

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Alpine Mammals of South America

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Abstract

The alpine environment of the Andes encompasses a vast and continuous extension of regions above tree line, in which three main ecoregions are identified: Paramo (north), Puna and Altiplano (center) and Southern Andes (South). Along this region, 200 species of mammals are found'; these belong to 10 orders and 27 families. Greater species richness is concentrated in two different areas, one at the ecotone between the Puna and the Yungas Montane forest, and the other within the southern portion of the Paramo. Both regions share species that are endemic or have their main distribution in the alpine or are broadly distributed species that only marginally reach high elevations.

Rodent species represent almost 70% of all Andean mammals, followed by bats and carnivores, which account for 8% and 5% respectively. Bats are only marginally present in the high Andes, whereas rodents encompass >40% of their range along the high Andes.

Andean mammals face several conservation threats, related mainly with habitat loss or transformation, climate change and invasive species introduction. Among Andean species, near 20% have some degree of conservation concern, while 15% are considered data deficient.

Introduction

The South American Andes extend over a north-south length of 8500 km, and are the world's longest mountain chain, with an elevation range from 700 to 7000 m asl. Within this region, three major geographical units can be identified: The Northern, the Central, and the Southern Andes (Sempere et al., 2008). Between the NA and CA, there is a transition zone termed "Amotape-Huancabamba". Its geography and topography provide an excellent scenario for the study and understanding of species distribution and biodiversity patterns.

The Andean uplift played an important role in the historical diversification of the Neotropical biota. It served as a source of new high elevation habitats (Young et al., 2007). It acted as a vicariant barrier, by promoting isolation of lowland organisms on either side of the mountains. It also represented a N–S corridor for several species (Patterson et al., 2012) and it generated a heterogeneous mosaic of habitats and micro-habitats (montane and inter montane valleys) where colonization and differentiation could occur. All these features contributed to the high diversity and endemicity of this region (Novillo and Ojeda, 2012; Ceballos and Ehrlich, 2006; Maestri and Patterson, 2016).

The alpine environment of the Andes encompasses a vast and continuous extension of regions above tree line (Fig. 1A). To the north, this environment tends to be wetter and fragmented (Peru to Venezuela), where they are called "páramos." From southern Peru to central Argentina, the high-elevation communities are termed "puna" and the portion that extends across western Bolivia is

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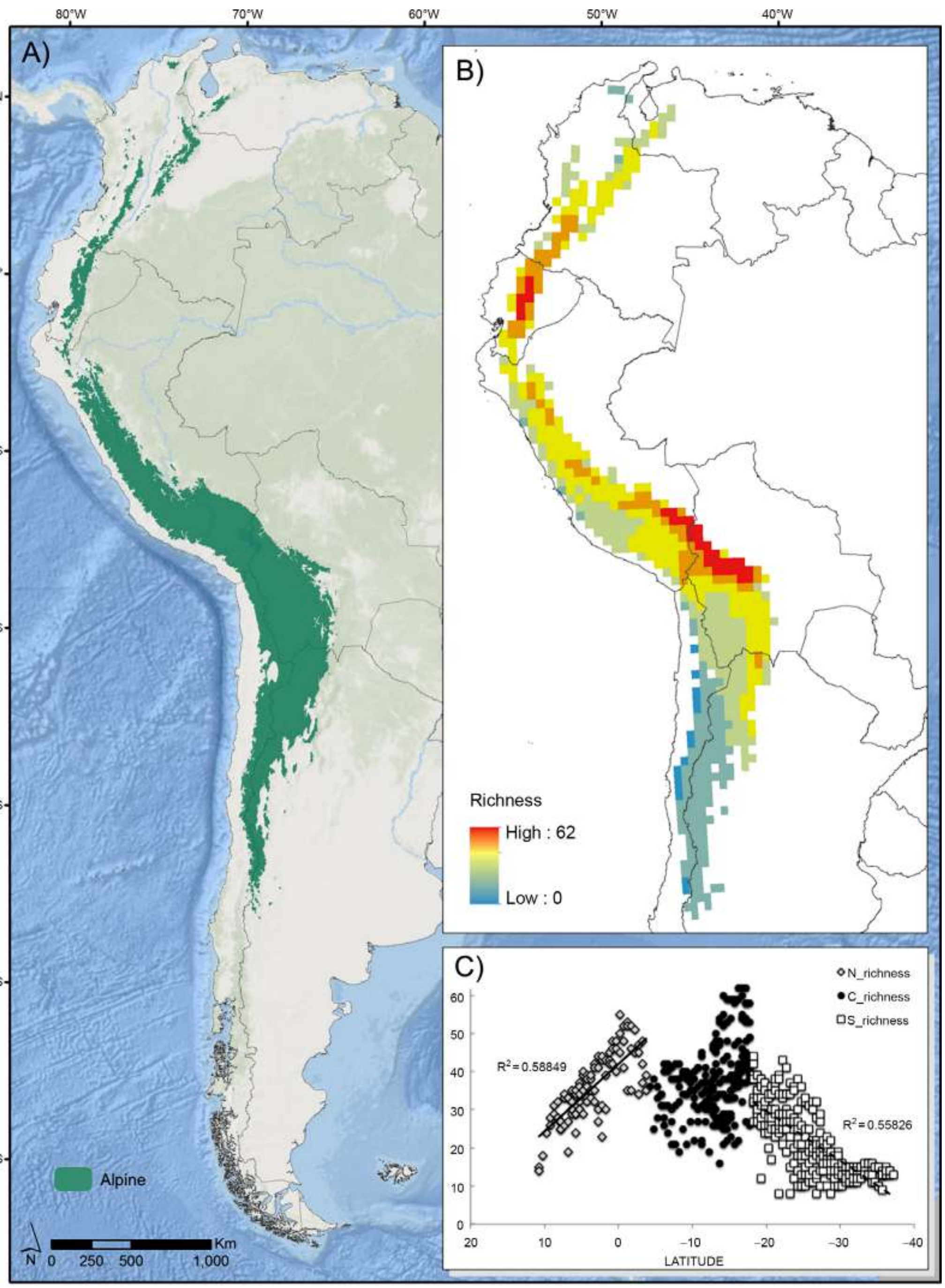

Fig. 1 (A) Alpine region along the Andes. (B) Alpine mammals richness. (C) Relationship between richness and latitude, using Alpine mammals separated into three groups: (1) N_richness—northern group (above the Amotape-Huancabamba depression); (2) C_richness—central group; (3) S_richness—southern group (below 20°S).

called "Altiplano"; both regions constitute a continuous arid province. The transitional communities above 3000 m in central Peru are known as "jalca". Finally, the Southern Andes include the remaining Andean zones south of 29°S. Here, elevations tend to decrease from North to South (Pankhurst and Herve, 2007).

The Páramo comprises a number of neotropical high altitude grassland ecosystems, mainly in the upper parts of the Northern Andes. Its vegetation is mainly dominated by tussock grasses, dwarf shrubs, cushion plants and other forms of vegetation adapted to the cold, wind and intense ultra-violet radiation found at high altitudes. This region houses some rare and large species of mammals, such as the spectacled bear (*Tremarctos ornatus*), the mountain tapir (*Tapirus pinchaque*) and the white-tailed deer

(*Odocoileus virginianus*) (Kattan et al., 2004). Several large mammals of the Paramos are susceptible of local extinction or are characterized as endangered (Diaz et al., 1997). Additionally some studies have been done on Páramo rabbits (*Sylvilagus brasiliensis andinus*), and on the diversity and distribution of small mammals (Kattan et al., 2004). The Northern Andes are considered a hotspot for restricted-range species (those 25% of species with the smallest ranges), which places a high conservation status on this region (Ceballos and Ehrlich, 2006). In general, the Paramos are inhabited by almost 25 mammal species, most of which are rodents (Diaz et al., 1997).

Puna and Altiplano are the most arid portion of the alpine environment and they are also considered the oldest. These regions are considered a mixture of heterogeneous habitats, with marked zonal vegetation.

The biogeographical history of several species supports the antiquity of the Altiplano. Among the South American Camelids, the Vicugna shows a demographic expansion associated with the last major glacial event of the Pleistocene, an indication of former refugia (Marín et al., 2008). Also, the Guanacos show that the Puna and Altiplano acted as a geographic barrier between populations of the Northwest (Sechura and Atacama desert) and the Southeast (South from Bolivia) (Marín et al., 2008). Rodents also show the same pattern; Phyllotine rodents exhibit ancestral character states and basal positions on phylogenies, whereas lowland taxa tend to exhibit derived characters (Spotorno et al., 2001).

Several parallel ranges shape the Southern Andes: the Cordillera Principal, Cordillera Frontal and the Pre-cordillera. The highest elevational limits of the vegetation in this area are found at approximately 5000 m asl in the north and 3000 m in the south. The vertical relief is extremely abrupt and some of the highest peaks of the Andes occur in its northern portion. In the south, elevations generally decrease to <3000 m, but high volcanoes are frequent. Permanent snow, ice caps and glaciers are found in the summits of these elevations. The Southern Alpine Andes are rich in endemic plants (Luebert and Weigend, 2014), though this does not hold true for mammals. Most mammal species have large geographic ranges, extending north into the Puna and eastward into the Monte Desert and Patagonia (Novillo and Ojeda, 2012). Some endemic or near-endemic mammals are small ground living species, such as the rodents of the genus *Euneomys and Abrothrix andina* (Ojeda et al., 2015b).

Although it is commonly considered that cold-adapted ecosystems such as high mountain ranges are robust and change slowly compared to other ecosystems. However, they are especially sensitive to threats associated with climate change and land use changes (Nogués-Bravo et al., 2007, 2008).

The purpose of this contribution is to characterize the composition, distribution and conservation of the high Andean range mammal fauna.

Distribution Patterns

Along the Andes we registered 200 species of mammals, representing 10 orders and 27 families (**Table 1**). Species richness was higher at the ecotone between the Puna and the Yungas Montane forest, and within the southern portion of the Paramo (**Fig. 1**B). Below 20°S, there is a clear and sharp monotonic decreasing pattern, which also is shown in an East–West richness decline (**Fig. 1**B). When richness is evaluated along a north south transect, it is clear that richness decreases with increasing latitude from the Equator, both to the north and to the south from 20°S (**Fig. 1**C). The central and southern regions show an east to west decrease in species richness; meanwhile the northern region shows the opposite trend.

Rodents represent almost 70% of all Andean mammals, followed by bats and carnivores, which account for 8 and 5% respectively (**Fig. 2**A). Mean distributional range of all mammalian orders identified from the Andes accounted for less than half % of their overall ranges as a whole (**Fig. 2**B). A total of 19% of species can be considered regionally restricted or endemic (alpine range $>70\%$, 39 species). Indeed, most of the species have broad distributions that include the alpine environment to some extent, in some cases just marginally (see section **Order Accounts**).

Andean environments are potentially threatened by several anthropogenic factors, such as climate change and land use change, among others. Therefore, we expect that conservation concerns of several alpine species will increase in future. Among endangered species are the emblematic species, mountain tapir (*Tapirus pinchaque*), the only alpine representative of the order Perissodactyla, almost 20% carnivores, 5% of Chiroptera and 5% of Rodentia. If conservation categories such as 'near threatened' or 'vulnerable' are included, 40% of carnivores, 15% of Chiroptera and Didelphimorphia, 50% of Paucituberculata and 15% of rodents found in the alpine Andes are included as species of conservation concern (**Fig. 2**C). Additionally, several mammal orders have a high proportion of species whose conservation status is poorly known, including almost 50% of Cingulata, 15% of Didelphimorphia and 20% of rodents. These are categorized as "data deficient" (**Fig. 2**C).

Order Accounts

Ungulates (Order Cetartiodactyla)

The order is represented by two families (Camelidae and Cervidae), which encompass six genera and eight species (**Fig. 3**A). Among them only three registered $>50\%$ of their ranges along the Alpine Andes, and the rest registered $<30\%$ (**Fig. 3**B). Of these, 30% of camelids and 80% of the cervids are considered vulnerable of extinction (**Fig. 3**C).

Table 1 Alpine mammal species.

Order	*Family*	*Genus*	*Species*	*IUCN*	*% alpine range*
Carnivora	Canidae	Lycalopex	*Pseudalopex culpaeus*	LC	34
	Felidae	Leopardus	*Leopardus colocolo*	NT	19
			Leopardus jacobita	EN	74
		Puma	*Puma concolor*	LC	5
	Mephitidae	Conepatus	*Conepatus chinga*	LC	14
	Mustelidae	Galictis	*Galictis cuja*	LC	6
		Mustela	*Mustela frenata*	LC	5
	Procyonidae	Nasua	*Nasua narica*	LC	11
		Nasuella	*Nasuella meridensis*	EN	16
			Nasuella olivacea	NT	21
	Ursidae	Tremarctos	*Tremarctos ornatus*	VU	19
Cetartiodactyla	Camelidae	Lama	*Lama guanicoe*	LC	19
		Vicugna	*Vicugna vicugna*	LC	87
	Cervidae	Hippocamelus	*Hippocamelus antisensis*	VU	96
		Mazama	*Mazama bricenii*	VU	18
			Mazama chunyi	VU	20
			Mazama rufina	VU	25
		Odocoileus	*Odocoileus virginianus*	LC	4
		Pudu	*Pudu mephistopheles*	VU	51
Chiroptera	Molossidae	Mormopterus	*Mormopterus kalinowskii*	LC	39
			Mormopterus phrudus	VU	75
		Tadarida	*Tadarida brasiliensis*	LC	12
	Phyllostomidae	Anoura	*Anoura geoffroyi*	LC	6
		Artibeus	*Artibeus fraterculus*	LC	27
		Chiroderma	*Chiroderma salvini*	LC	14
		Lonchophylla	*Lonchophylla hesperia*	NT	23
		Platyrrhinus	*Platyrrhinus dorsalis*	LC	7
			Platyrrhinus nigellus	LC	44
		Sturnira	*Sturnira aratathomasi*	LC	9
			Sturnira luisi	LC	10
			Sturnira magna	LC	16
	Vespertilionidae	Eptesicus	*Eptesicus andinus*	LC	16
		Histiotus	*Histiotus macrotus*	LC	44
			Histiotus montanus	LC	12
		Myotis	*Myotis atacamensis*	EN	20
			Myotis dinellii	LC	9
			Myotis keaysi	LC	12
			Myotis oxyotus	LC	19
Cingulata	Dasypodidae	Chaetophractus	*Chaetophractus vellerosus*	LC	21
		Dasypus	*Dasypus pilosus*	DD	46
Didelphimorphia	Didelphidae	Didelphis	*Didelphis pernigra*	LC	32
		Gracilinanus	*Gracilinanus aceramarcae*	LC	54
			Gracilinanus dryas	LC	12
		Marmosops	*Marmosops juninensis*	VU	22
		Monodelphis	*Monodelphis osgoodi*	LC	29
		Thylamys	*Thylamys pallidior*	LC	30
			Thylamys venustus	DD	18
Eulipotyphla	Soricidae	Cryptotis	*Cryptotis brachyonyx*	DD	6
			Cryptotis equatoris	LC	58
			Cryptotis meridensis	LC	18
			Cryptotis montivaga	LC	61
			Cryptotis peruviensis	DD	20
			Cryptotis squamipes	LC	26
			Cryptotis tamensis	LC	30
			Cryptotis thomasi	LC	26
Lagomorpha	Leporidae	Sylvilagus	*Sylvilagus brasiliensis*	LC	1
Paucituberculata	Caenolestidae	Caenolestes	*Caenolestes caniventer*	NT	34
			Caenolestes convelatus	VU	16
			Caenolestes fuliginosus	LC	28
		Lestoros	*Lestoros inca*	LC	21

Table 1 Alpine mammal species.—cont'd

Order	*Family*	*Genus*	*Species*	*IUCN*	*% alpine range*
Perissodactyla	Tapiridae	Tapirus	*Tapirus pinchaque*	EN	41
Rodentia	Abrocomidae	Abrocoma	*Abrocoma bennettii*	LC	19
			Abrocoma cinerea	LC	83
			Abrocoma famatina	DD	46
			Abrocoma shistacea	LC	16
			Abrocoma vaccarum	DD	100
		Cuscomys	*Cuscomys ashaninka*	DD	77
	Caviidae	Cavia	*Cavia patzelti*	DD	43
			Cavia tschudii	LC	56
		Galea	*Galea comes*	DD	66
		Microcavia	*Microcavia niata*	LC	98
			Microcavia shiptoni	NT	65
	Chinchillidae	Chinchilla	*Chinchilla chinchilla*	EN	89
		Lagidium	*Lagidium ahuacaense*	DD	7
			Lagidium viscacia	LC	46
	Cricetidae	Abrothrix	*Abrothrix andina*	LC	89
			Abrothrix illutea	NT	24
			Abrothrix jelskii	LC	94
		Aegialomys	*Aegialomys xanthaeolus*	LC	15
		Aepeomys	*Aepeomys lugens*	LC	26
		Akodon	*Akodon affinis*	LC	20
			Akodon albiventer	LC	96
			Akodon boliviensis	LC	84
			Akodon fumeus	LC	27
			Akodon kofordi	LC	34
			Akodon lutescens	LC	56
			Akodon mimus	LC	69
			Akodon mollis	LC	33
			Akodon siberiae	NT	27
			Akodon simulator	LC	6
			Akodon spegazzinii	LC	21
			Akodon subfuscus	LC	79
			Akodon surdus	VU	43
			Akodon torques	LC	37
			Akodon varius	DD	16
		Andinomys	*Andinomys edax*	LC	68
		Anotomys	*Anotomys leander*	VU	68
		Auliscomys	*Auliscomys boliviensis*	LC	88
			Auliscomys pictus	LC	95
			Auliscomys sublimis	LC	98
		Calomys	*Calomys boliviae*	LC	9
			Calomys lepidus	LC	91
			Calomys musculinus	LC	7
			Calomys sorellus	LC	92
		Chibchanomys	*Chibchanomys orcesi*	DD	54
		Chilomys	*Chilomys instans*	LC	29
		Chinchillula	*Chinchillula sahamae*	LC	99
		Eligmodontia	*Eligmodontia puerulus*	LC	93
		Euneomys	*Euneomys mordax*	LC	17
		Galenomys	*Galenomys garleppi*	DD	100
		Graomys	*Graomys edithae*	DD	16
		Ichthyomys	*Ichthyomys hydrobates*	NT	19
			Ichthyomys stolzmanni	DD	39
		Microryzomys	*Microryzomys altissimus*	LC	54
			Microryzomys minutus	LC	27
		Necromys	*Necromys amoenus*	LC	83
			Necromys lactens	LC	21
			Necromys punctulatus	DD	39

(Continued)

Table 1 Alpine mammal species.—cont'd

Order	*Family*	*Genus*	*Species*	*IUCN*	*% alpine range*
		Neomicroxus	*Akodon bogotensis*	LC	30
			Akodon latebricola	VU	68
		Neotomys	*Neotomys ebriosus*	LC	92
		Nephelomys	*Nephelomys albigularis*	LC	20
			Nephelomys levipes	LC	38
			Nephelomys meridensis	LC	19
		Neusticomys	*Neusticomys monticolus*	LC	40
			Neusticomys mussoi	EN	12
		Oligoryzomys	*Oligoryzomys andinus*	LC	76
			Oligoryzomys arenalis	LC	11
			Oligoryzomys destructor	LC	29
			Oligoryzomys griseolus	LC	29
		Oxymycterus	*Oxymycterus hiska*	LC	13
			Oxymycterus paramensis	LC	38
		Phyllotis	*Phyllotis andium*	LC	42
			Phyllotis anitae	DD	30
			Phyllotis caprinus	LC	63
			Phyllotis definitus	EN	80
			Phyllotis haggardi	LC	61
			Phyllotis limatus	LC	10
			Phyllotis magister	LC	79
			Phyllotis osgoodi	DD	84
			Phyllotis osilae	LC	88
			Phyllotis wolffsohni	LC	29
			Phyllotis xanthopygus	LC	50
		Punomys	*Punomys kofordi*	VU	100
			Punomys lemminus	VU	100
		Reithrodontomys	*Reithrodontomys mexicanus*	LC	24
		Rhipidomys	*Rhipidomys caucensis*	DD	12
			Rhipidomys fulviventer	LC	24
			Rhipidomys venustus	LC	30
		Sigmodon	*Sigmodon inopinatus*	VU	76
		Thomasomys	*Thomasomys apeco*	VU	52
			Thomasomys aureus	LC	28
			Thomasomys baeops	LC	43
			Thomasomys caudivarius	LC	32
			Thomasomys cinereiventer	LC	24
			Thomasomys cinereus	LC	28
			Thomasomys cinnameus	LC	70
			Thomasomys daphne	LC	26
			Thomasomys eleusis	LC	14
			Thomasomys erro	LC	78
			Thomasomys gracilis	NT	25
			Thomasomys hudsoni	DD	44
			Thomasomys hylophilus	EN	8
			Thomasomys incanus	VU	58
			Thomasomys ischyrus	VU	31
			Thomasomys kalinowskii	VU	46
			Thomasomys ladewi	LC	52
			Thomasomys laniger	LC	21
			Thomasomys macrotis	VU	57
			Thomasomys monochromos	EN	38
			Thomasomys niveipes	LC	35
			Thomasomys notatus	LC	41
			Thomasomys onkiro	VU	12
			Thomasomys oreas	LC	31
			Thomasomys paramorum	LC	57
			Thomasomys praetor	DD	46
			Thomasomys pyrrhonotus	VU	10
			Thomasomys rosalinda	DD	40

Table 1 Alpine mammal species.—cont'd

Order	*Family*	*Genus*	*Species*	*IUCN*	*% alpine range*
			Thomasomys silvestris	LC	68
			Thomasomys taczanowskii	LC	29
			Thomasomys ucucha	VU	84
			Thomasomys vestitus	LC	38
			Thomasomys vulcani	DD	52
	Ctenomyidae	Ctenomys	*Ctenomys frater*	LC	29
			Ctenomys fulvus	LC	83
			Ctenomys knighti	DD	34
			Ctenomys leucodon	LC	100
			Ctenomys lewisi	LC	63
			Ctenomys opimus	LC	99
			Ctenomys peruanus	LC	100
			Ctenomys saltarius	DD	33
			Ctenomys scagliai	DD	22
			Ctenomys tulduco	DD	22
	Cuniculidae	Cuniculus	*Cuniculus taczanowskii*	NT	14
	Echimyidae	Dactylomys	*Dactylomys peruanus*	DD	9
		Olallamys	*Olallamys albicauda*	DD	16
	Erethizontidae	Coendou	*Coendou quichua*	DD	8
			Coendou rufescens	LC	11
	Octodontidae	Octodontomys	*Octodontomys gliroides*	LC	66
	Sciuridae	Sciurus	*Sciurus pucheranii*	DD	13

Taxonomy, conservation status and % of their total range along the high Andes.
EN, endangered; *LC*, least concern; *NT*, near threaten; *VU*, vulnerable. IUCN red list categories. *DD*, data deficient.

Family Camelidae

South American Camelids encompass four species "Llama and Alpaca" (both domestic) and "Guanaco and Vicuña" (wild), all widely distributed in South America. Wild camelids form social groups that alive in family groups, groups of bachelors and solitary individuals (Young and Franklin, 2004). Their mating system is polygynous for defense of resources, in which adult males defend territories of high forage quality and low predator density (Young and Franklin, 2004).

Camelids are intimately connected with Andean culture. At present, human use activities such as live capture and shearing could play an important role in the conservation of these species and their habitat (Carmanchahi et al., 2014).

The Guanaco (*Lama guanicoe*) ranges from northern Peru (8°30′ S) to southern Tierra del Fuego (55°S), and from sea level up to 4857 m asl (Baldi et al., 2016). Historically, this species experienced significant population decline (Wheeler, 2012), and now its populations can be considered stable, mainly along its southern distribution (Schroeder et al., 2014). Guanaco habitat is characterized by seasonal climates in regions with low plant productivity. They are considered the largest (widely distributed) endemic herbivore of South-America, due to their anatomy, behavior and physiology (Puig et al., 2014; Ovejero et al., 2016).

Vicuñas (*Vicugna vicugna*) are restricted to fragmented areas of high elevation between 9°S and 29°S latitude in the Andes (Wheeler, 2012; and reference therein). DNA data suggest that their current distribution is the result of a westward expansion associated with glacial events during the Late Pleistocene 14–12,000 years ago (Wheeler, 2012).

Vicuña habitats include shallow wetlands "Vegas", halophytic plant communities, steppes, prairies, and rolling shrub steppes (tolares) (Arzamendia and Vila, 2014). Vegas are intensively used by Vicuñas, given that they are obligate drinkers (Franklin, 2011). Water availability influences daily activity patterns, while in the night Vicuñas move to hillsides to avoid predation from pumas (Donadio and Buskirk, 2016). The Vicuña is considered a generalist herbivore that behaves as a facultative grazer that can also include shrubs in its diet (Mosca Torres and Puig, 2012; Mosca Torres et al., 2015).

Family Cervidae

Latin America has largest deer diversity in the world, with seven genera and 18 species thus far described (Wemmer, 1998). The alpine environment has 7 species in 4 genera (*Hippocamelus*, *Mazama*, *Odoecoileus* and *Pudu*).

The genus *Hippocamelus* comprises two species, the "Taruka" (*Hippocamelus antisensis*), and the "Huemul" (*Hippocamelus bisulcus*). Taruka distribution extends though the highlands of the Andes from Peru to NE Chile (Barrio, 2013; Barrio et al., 2017), while the Huemul is endemic to Chile and Argentina (Vila et al., 2006). Both species' distributions are fragmented with populations isolated from each other (Corti et al., 2011) and there is evidence of a decreasing population trend (Barrio et al., 2017; Flueck and Smith-Flueck, 2006). Tarukas are found between 2000 and 5000 m asl in rock outcrops within grassland vegetation and nearby water sources. Meanwhile, Huemul ranges from sea level up to 3000 m elevation, and is found mainly at the forest edge (*Nothofagus spp.*). Predation can be a major limiting factor and may even threaten species population viability (Elbroch and Wittmer, 2013). Several

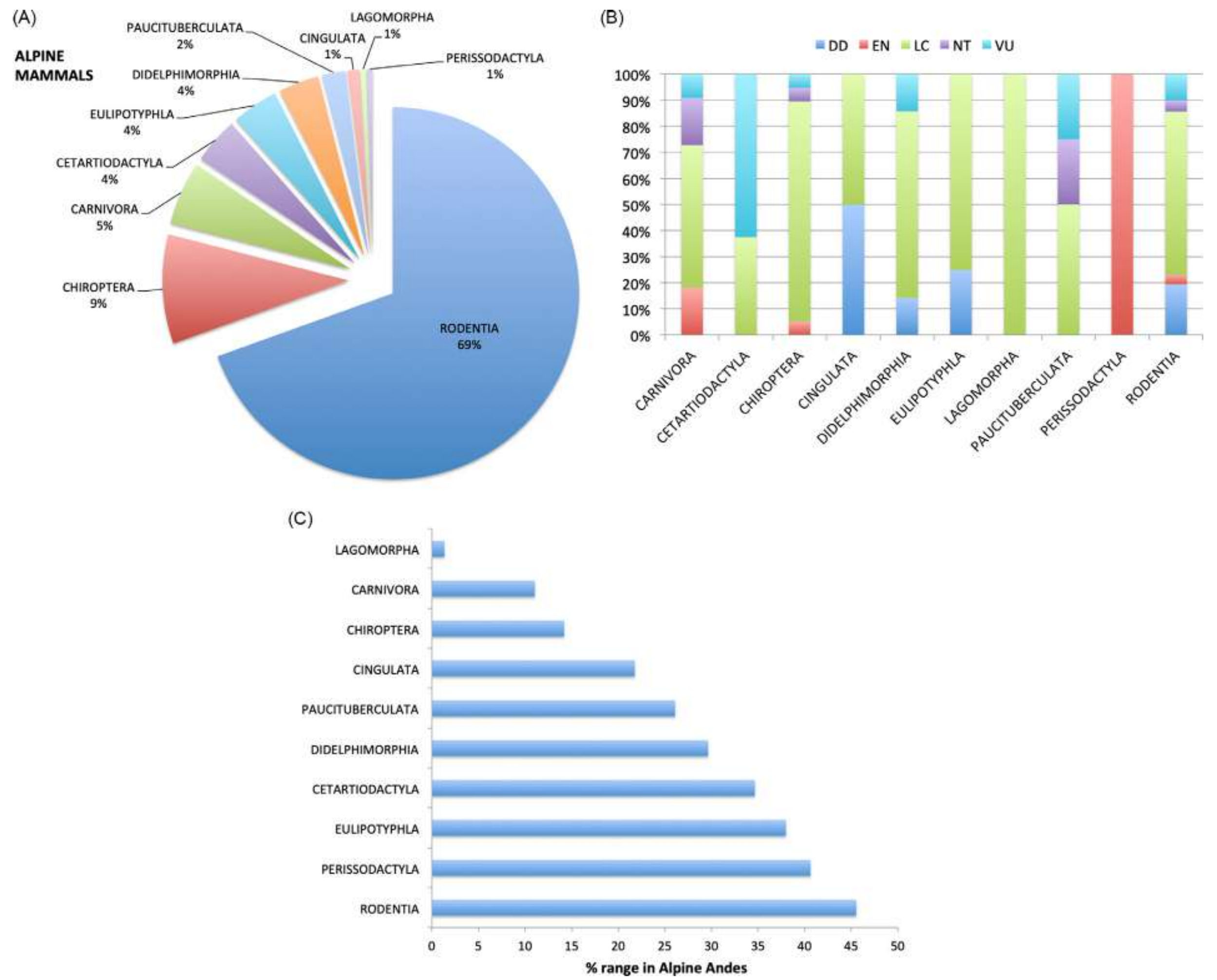

Fig. 2 (A) Percentage of High Andean mammals by Order. (B) Conservation status, percentage of species in each IUCN red list category. (C) Percentage of the species range encompass along the alpine region.

factors have been hypothesized to explain these species' populations failure to recover (cattle, exotic trees, irrational forestry, exotic animals, illegal hunting, diseases, dogs, reduced numbers, loss of winter range) (Flueck and Smith-Flueck, 2006).

The genus *Mazama* has been the focus of a broad taxonomic debate. DNA studies suggest that this genus is polyphyletic (Gutiérrez et al., 2017). Three species of *Mazama* are found in the alpine Andes: *Mazama bricenii, Mazama chunyi* and *Mazama rufina*. The ecology and general biology of the genus *Mazama* is unknown, although they seem to be solitary, active day and night, and with a browser/frugivore diet. In general, these species exhibit a decreasing population trend and are in need of further research.

Mazama bricenii "Mérida Brocket" is patchily distributed along the high Andes (1000–3500 m asl) in northern Colombia and western Venezuela, mainly along montane forests and in the Paramo (Lizcano and Alvarez, 2016). *Mazama chunyi* "Peruvian Dwarf Brocket" inhabits the highlands of southern Peru and northern Bolivia. Its current distribution and abundance need to be further assessed (Rumíz and Pardo, 2010). *Mazama rufina* "Dwarf Red Brocket" is found along the montane forest and the Paramos of Colombia, Ecuador and Peru, between 1500 and 3500 m asl.

Odoecoileus virginianus "White tailed Deer" is a broadly distributed species that extends along the North and South American continents (Smith, 1991). In South America eight subspecies have been described, (Smith, 1991; Moscarella et al., 2003), among which 3 are present at the high Andes: (1) *O. v. goudotii* (Highlands Andes of Venezuela, Colombia, Ecuador and Northern Peru); (2) *O. v. ustus* (Andean region of Ecuador and Colombia); (3) and *O. v. peruvianus* (Peru and Bolivia, excluding amazon region) (Smith, 1991). South American populations are declining (Gallina and López-Arevalo, 2016), and conservation of the Andean subspecies is strongly suggested (Moscarella et al., 2003). White tailed deer diet is seasonal, and it can be considered as an opportunistic forager in the Paramos.

Pudu mephistopheles "Northern Pudu" is the only species of the genus present in the high Andes. Its range is fragmented, and it inhabits the montane forests and Paramos of Colombia, Ecuador and Peru. There is evidence of a high degree of isolation between

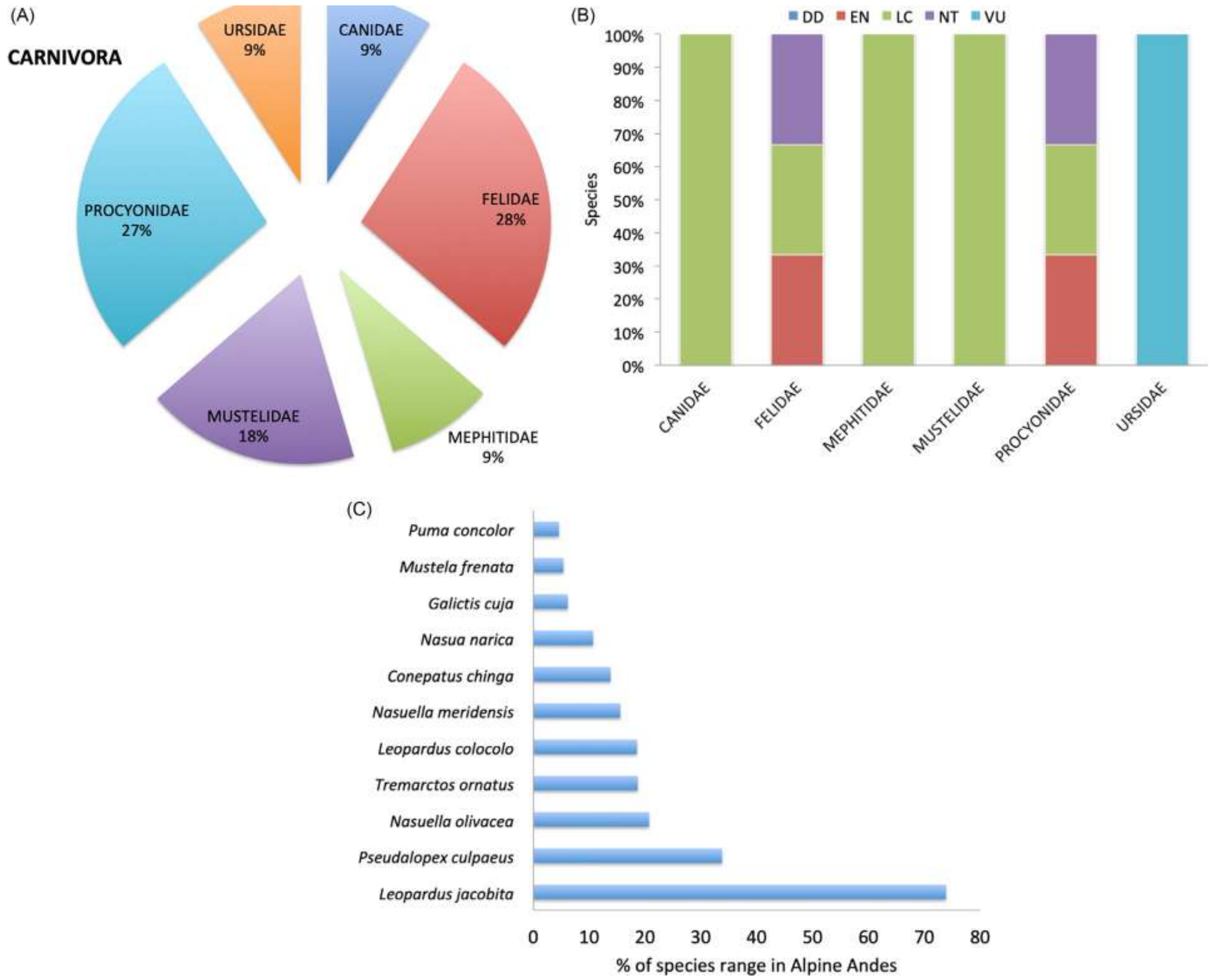

Fig. 3 (A) Percentage of High Andean carnivores by family. (B) Conservation status, percentage of species in each IUCN red list category. (C) Percentage of the species range encompass along the alpine region.

populations (Loyola et al., 2010). Northern Pudu was intensively exploited from the 1950s to early 1980s. However, the current threats are mainly habitat conversion and predation by domestic dogs.

Carnivores (Order Carnivora)

Six carnivore families are found along the high Andes, comprising 10 genera and 11 species (Fig. 4A). Among them, Felidae (28% of the species) and Procyonidae (27%) are the best-represented. The Andean cat is the only carnivore that can be considered as endemic to the high Andes, with most of its range confined to high elevations (Fig. 4B). In general, most carnivores have only 15 to 20% of their ranges in the Andes (Fig. 4B). The families Felidae and Procyonidae have 30% of their species categorized as endangered, with another 30% considered vulnerable (Fig. 4C). The only bear (family Ursidae) found in the high Andes is the Andean Bear (*Tremarctos ornatus*); this species is categorized as vulnerable.

The family Canidae is represented by the "Culpeo" (*Lycalopex culpaeus*), which have a broad distribution throughout South America, from sea level to 4800 m asl (Ramírez-Chaves et al., 2013). Its population trend is stable, but culpeos are been persecuted throughout their range due to human conflicts (Lucherini and Merino, 2008). Also there is evidence for negative effects with coexistence with the puma (Travaini et al., 2007).

The family Felidae is represented in the Andes only by the "Pampas cat" (*Leopardus colocolo*), the "Andean cat" (*Leopardus jacobita*) and the "Puma or cougar" (*Puma concolor*). The pampas cat has a broad distribution in South America. Along the Andes, populations seem to be stable and may even reach high densities (0.74–0.78 individuals/km^2), mainly along productive habitat patches (Lucherini et al., 2016). In the high Andes this cat's diet is includes mountain viscacha and small rodents (Napolitano et al., 2008; Fajardo et al., 2014).

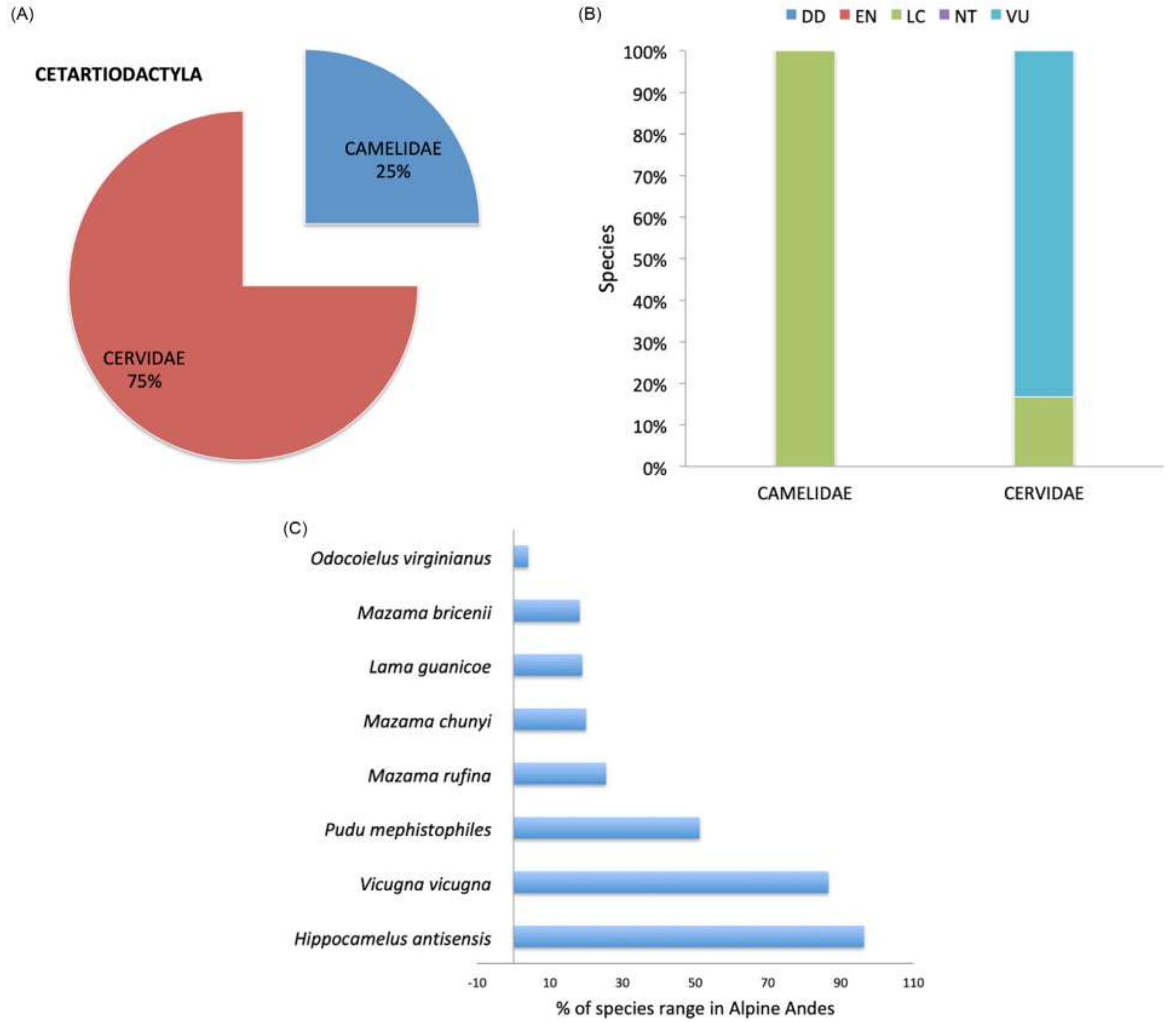

Fig. 4 (A) Percentage of High Andean ungulates by family. (B) Conservation status, percentage of species in each IUCN red list category. (C) Percentage of the species range encompass along the alpine region.

The Andean cat has a patchy distribution in the Andes, restricted to rocky habitats above 3600 m (Argentina, Bolivia, Chile and Peru) (Cossios and Angers, 2007; Novaro et al., 2010; Reppucci et al., 2011). Genetic studies confirm two isolated populations that can be considered as "Evolutionary Significant Units" (ESUs); also these studies confirm that the species has very low genetic diversity (Cossíos et al., 2012). The Andes cat may be considered as a habitat and diet specialist, with high proportions of rodents and mountain viscachas (*Lagidium spp.*) in its diet (Napolitano et al., 2008; Marino et al., 2010).

The puma is the largest carnivore of the region, with a broad distribution throughout the Americas. Due to conflicts with humans, pumas can be considered near threatened in specific places and have been categorized as least concern with a decreasing population trend by IUCN (Nielsen et al., 2015).

Ranges of several of these species overlap along the Andes (Lucherini et al., 2009), which may be leading to intraguild competition and a high degree of dietary overlap (Lucherini et al., 2008; Donadio and Buskirk, 2016). Evidence suggests a negative effect of competition among carnivores that may impact the most endangered species (Lucherini and Luengos Vidal, 2003; Napolitano et al., 2008). This competition among predators leads to ecological segregation by temporal partitioning (Lucherini et al., 2009).

The Procyonid family, "Coatis" extend along the northern Andes, from Northern Peru to Venezuela and display restricted or limited distributions (Helgen et al., 2009; González-Maya et al., 2011). The two species of *Nasuella* (*olivacea* and *meridensis*) were previously considered to be one, and the genus *Nasua* seems not to be monophyletic (Helgen et al., 2009). All three species of alpine procyonids exhibit decreasing population trends, mainly due to habitat loss (Helgen et al., 2009). There is little reliable information about their distribution, ecology, and biology (Balaguera-Reina et al., 2009). In general, the species are omnivorous, eating predominantly invertebrates and fruit (Rodríguez-Bolaños et al., 2000). Coatis are gregarious, with a complex social organization (Rodríguez-Bolaños et al., 2000).

The Molinas hog-nosed skunk, the only representative of Mephitidae family, has a broad distribution, from southern Peru to Chile and Argentina (Emmons et al., 2016). In general it is a common species with average densities of 3 individuals/km. It is a nocturnal and solitary, with a generalist diet (Donadio et al., 2004). It is categorized as least concern by IUCN, but is currently showing a decreasing population trend (Emmons et al., 2016).

Mustelids are represented by the Lesser grison and Long-tailed weasel. Both are considered as least concern for conservation (Helgen and Schiaffini, 2016; Helgen and Reid, 2016). The former is a broadly distributed species (from Southern Peru to Argentina and Chile), which is frequently found near water and open habitats (Poo-Muñoz et al., 2014). It is relatively rare in most habitats. Its diet consists of small and medium-sized vertebrates, with a predominance of introduced lagomorphs and native rodents. Lesser grisons are active during the day, but also at dusk and may also be nocturnal. The long-tailed weasel tends to be solitary or to live in small groups. It has the greatest geographical range among mustelids of the Western Hemisphere and inhabits a wide array of habitats and elevations (Sheffield and Thomas, 1997). Mismatch analyses suggest a longer genetic stability of long-tailed weasel lineages in southern versus northern habitats (Harding and Dragoo, 2012).

The spectacled or Andean bear is the only extant representative of the Ursidae in South America (Kattan et al., 2004). Its geographic distribution extends along the tropical Andes from Venezuela to Bolivia-Argentina and it occupies a variety of ecosystems (García-Rangel, 2012). Its range is severely fragmented (mostly in the northern part); this entails conservation problems for the species, including isolated and small populations, habitat loss, altitudinal movement limitations, etc. (Troya et al., 2004). Andean bears are omnivorous, though the meat proportion of their diet is rather low (Troya et al., 2004). Populations are on the decline mainly due to habitat loss and fragmentation (Kattan et al., 2004; García-Rangel, 2012). Conservation actions are mainly focused on the preservation or development of habitat corridors for the species (Yerena and García-Rangel, 2010).

Bats (Order Chiroptera)

Chiroptera are the second most speciose order of mammals. Along the high Andes we registered 3 families, 11 genera and 19 species of bats (**Fig. 5**A), which in general encompass $<20\%$ of their ranges along the high Andes (**Fig. 5**B). Little information about habitat, activity patterns and general ecology is available for Andean bats. The Incan mastiff bat (*Mormopterus phrudus*) has most of its range (75%) in the high Andes, although this species is only known from the type locality in Cusco, Peru. There are few records of bat species above 3500 m, with the probable exception of *Histiotus montanus* (Handley Jr. and Gardner, 2008). Conservation status among Andean bats reveals that, among the family Vespertilionidae, 12% of the species are considered endangered, 10% of Phyllostomidae are near threatened and 30% of Molossidae are categorized as vulnerable (**Fig. 5**C). The Andean bat community is characterized by reduced species richness and little endemism (Mena et al., 2011).

Armadillos (Order Cingulata)

This order includes only the family Dasypodidae, commonly known as "armadillos or quirquinchos". We found two genera that reach the high Andes region, each represented by a single species. The screaming hairy armadillo (*Chaetophractus vellerosus*) is distributed in the center and south of Bolivia (Tarifa and Romero-Muñoz, 2009), west of Paraguay and north of Argentina (Abba and Superina, 2010), generally in arid and semi-arid environments. The subspecies *C. v. vellerosus*, present in the Puna of Bolivia and Argentina, occurs at altitudes from sea level to 4600 m asl, and almost 20% of its distribution falls within the high Andes. It is considered, as least concern for conservation and its population trend is stable. However, this species is heavily hunted and its habitat has been intensively transformed (Superina et al., 2014). Its diet is omnivorous and it constructs burrows for refuge (Abba and Cassini, 2008). The hairy long-nosed armadillo (*Dasypus pilosus*) has been recorded only from the southwestern Peruvian Andes, and its distribution probably reaches the high Andean environment (Superina et al., 2014). Both morphology and invertebrate ecology support the hypothesis that *Dasypus pilosus* likely bases its diet on soft-bodied invertebrates. More studies are necessary to clarify its ecology and distribution (Superina and Loughry, 2015).

Opossums (Order Didelphimorphia)

This order includes the majority of the living American marsupials (Gardner, 2008). All of them are included in the family Didelphinae. Six species occur in the Andes, representing four genera. Most of them reach the margins of high elevations, mainly due to its arboreal habits and ecophysiological aspects (**Fig. 6**A) The Andean white eared opossum (*Didelphis pernigra*) is found along the Andes from northwestern Venezuela and Colombia to the north of Argentina (rare along the Puna and Paramo environment). *Gracilinanus aceramarcae* has a narrow distributional range, with a significant proportion of its range in the high Andes (**Fig. 6**B). It has been found in the Cordillera Vilcabamba at 3350 m, in a mixed habitat consisting of pajonales, sphagnum bogs, mixed-species forest, and Polylepis forest on a "blocky" limestone substrate (Voss et al., 2005). The Wood-sprite Opossum (*Gracilinanus dryas)* is known from the Andes of Venezuela and Colombia, mainly in montane wet forest at elevations from 2300 to 4000 m asl. This species is not endangered but its population trend is decreasing (Pérez-Hernandez et al., 2016). Osgood's Short-tailed Opossum (*Monodelphis osgoodi*) is found in the eastern Andes in Perú and Bolivia from 1400 to 3500 m asl. Most records are from the montane forest; its presence on alpine regions is peripheral. This species is the least arboreal; its diet consists of insects, seeds and fruits (Nowak, 1999). Two species in the genus *Thylamys*, *T. venustus* and *T. pallidior* range into the high Andes. Both

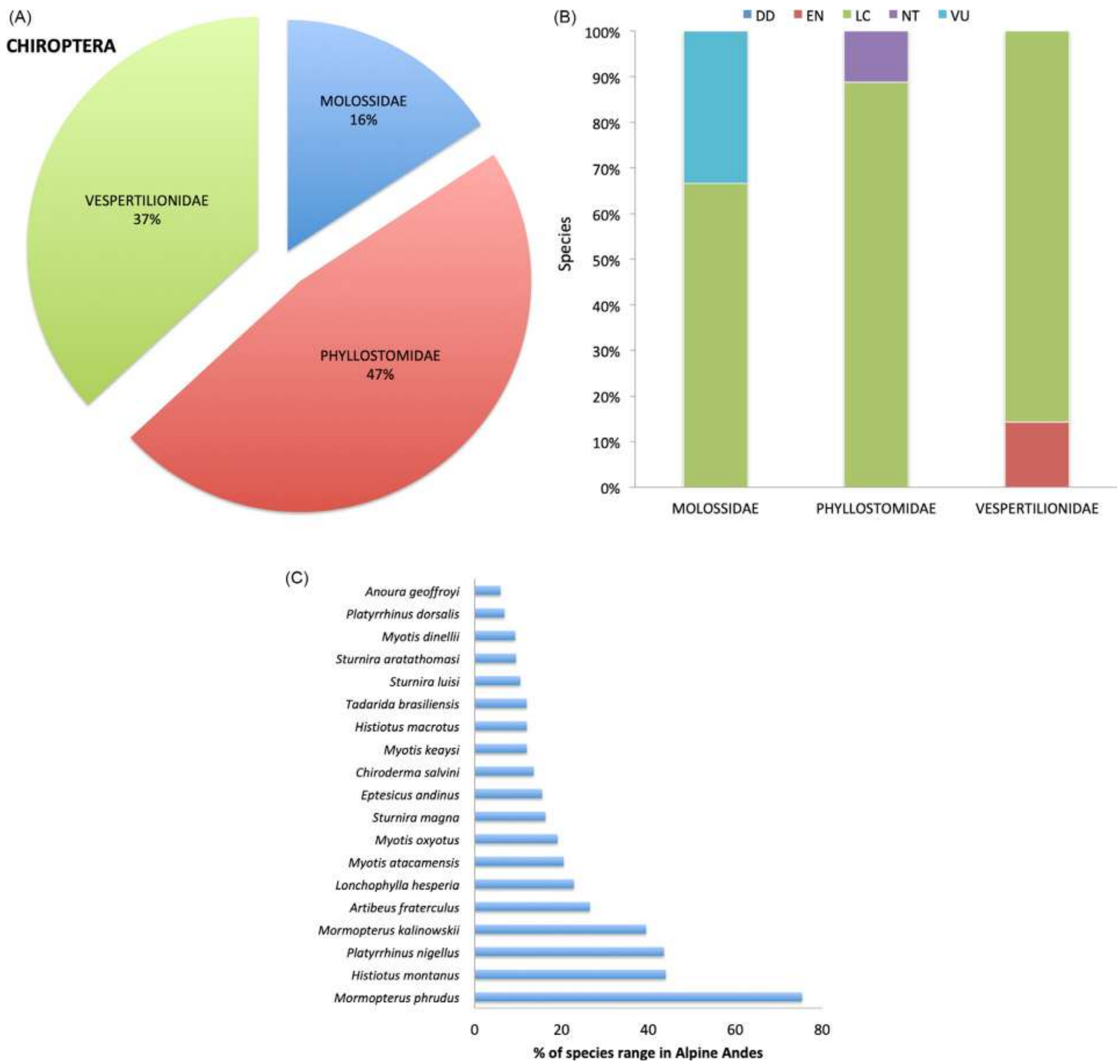

Fig. 5 (A) Percentage of High Andean bats by family. (B) Conservation status, percentage of species in each IUCN red list category. (C) Percentage of the species range encompass along the alpine region.

species have broad ranges in Argentina, Chile, Bolivia and Peru (Solari, 2003). The genus is in need of extensive taxonomic revision (Braun et al., 2005). Little information is available about *T. venustus*, so it is considered as data deficient in terms of conservation (Fig. 6B).

Shrews (Order Eulipothyphla)

Andean shrews are represented by the family Soricidae and the genus *Cryptotis*, which encompass 8 species. Their range extends from Venezuela to Peru north of the Huancabamba depression (Woodman and Péfaur, 2008). *Cryptotis* is known only from elevations above 1200 m in a variety of habitat types (Lower and Montane Forest, Paramo, and in disturbed forest and pasture lands). Taxonomic treatments of the genus *Cryptotis* partition the species among four informal species groups. Most South American shrews are members of the *C. thomasi-group*, which is distinguished by a number of derived characters. Among this group, *C. equatorius* and *C. motivaga* comprise >50% of their ranges along high Andes (Fig. 7). In general, most of the species are distributed along the lower and montane forests and extend only marginally over the Paramo (Woodman and Díaz de Pascual, 2004). There is no clear conservation concern among shrews, although there is little information about their natural history. *C. peruvensis* is considered as data deficient, mainly as it is only known from two specimens (Vivar et al., 1997).

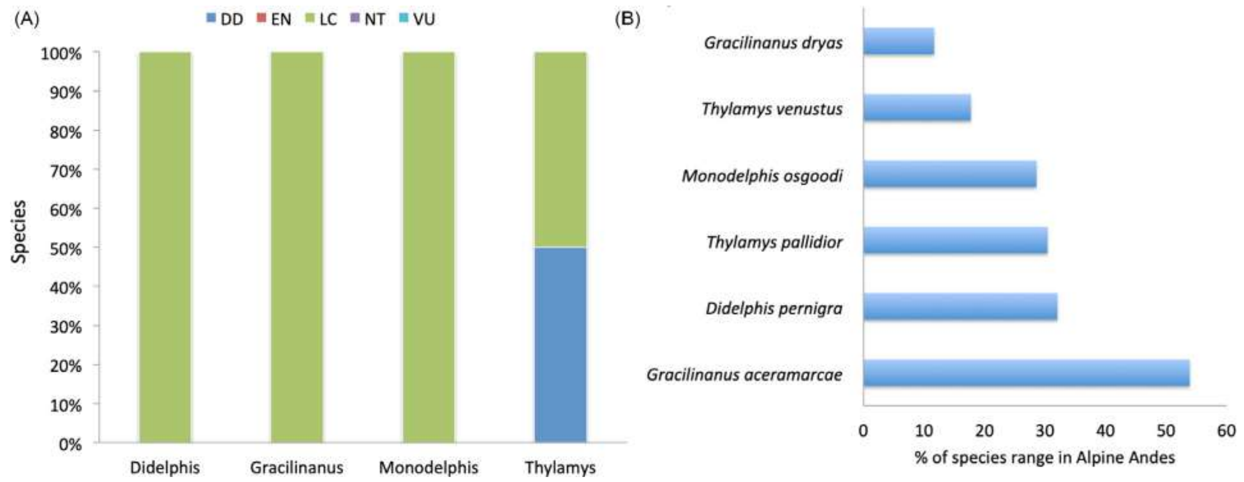

Fig. 6 Order Cingulata. (A) Conservation status, percentage of species in each IUCN red list category. (B) Percentage of the species range encompass along the alpine region.

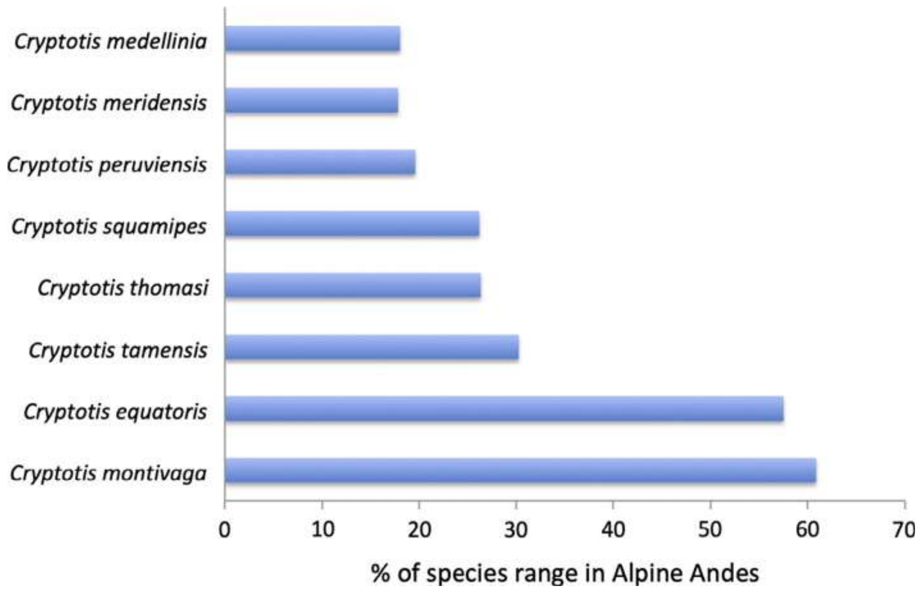

Fig. 7 Order Eulipothyphla. Percentage of the species range encompass along the alpine region.

Shrew Opossums (Order Paucituberculata)

This order is represented by one family (Caenolestidae), which comprises 3 genera, known only from South America. We list only two genera (*Caenolestes* and *Lestoros*) and 4 species that reaches high Andes elevations, and whose geographic range extends discontinuously from western Venezuela to Bolivia (Timm and Patterson, 2008; Patterson, 2015). All species registered $<40\%$ of their ranges along the Andes (Fig. 8A), generally they inhabit montane forest, near streams or water courses, and may reach the high elevations only marginally (Timm and Patterson, 2008; Patterson, 2015). Shrew opossums are mostly nocturnal, feeding on earthworms, flatworms, and several arthropods, both as larvae and adults (Patterson, 2015). *C. caniventer* and *C. convelatus* registered some conservation concerns, meanwhile *C. fuliginosus* and *Lestoros inca* are considered of least concern (Fig. 8B). Land transformation for agricultural purposes is among the mayor threats (Solari and Martínez-Cerón, 2015).

Páramo Rabbit (Order Lagomorpha)

The Páramo Rabbit, *Sylvilagus brasiliensis* has been classified as the subspecies *S b. meridensis*, which inhabits all Venezuelan and Colombian páramos (Durant, 1983); and *S B. andinus* is present at high elevations in Ecuador (Diersing and Wilson, 2017).

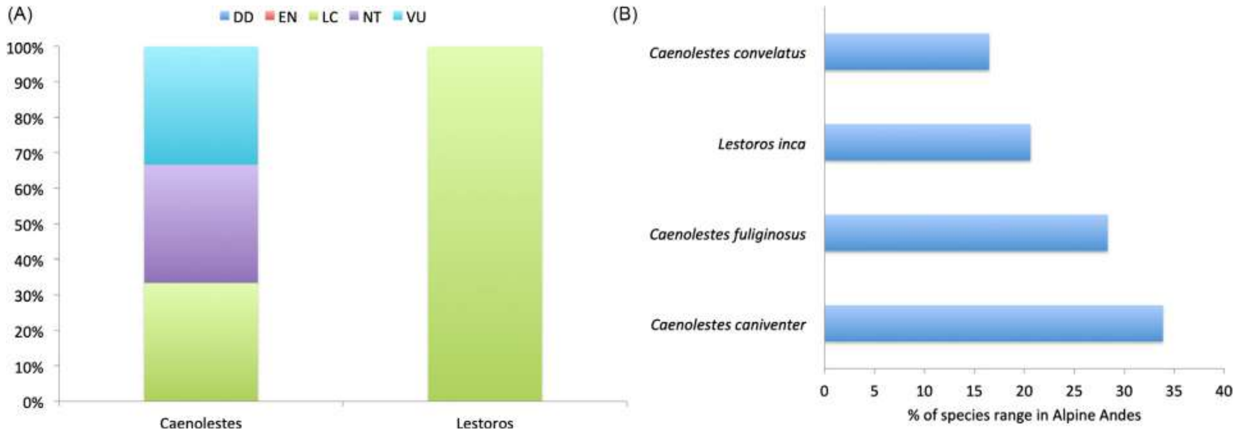

Fig. 8 Order Paucituberculata. (A) Conservation status, percentage of species in each IUCN red list category. (B) Percentage of the species range encompass along the alpine region.

Population density along Venezuela Páramos was estimated at 2.85 rabbits per ha. (Durant, 1983) and in Ecuador it ranged from 23 to 92 individuals/ha. Abundance is strongly associated with vegetation structure (García et al., 2016), since higher complexity and higher diversity of the vegetation leads to more possible refuges for rabbits to avoid predators and greater diversity of diet items. The size and abundance of rabbits make them an important Páramo prey species (García et al., 2016), therefore its presence and abundance are important for community structure (Durant, 1983). The Páramo rabbit has several adaptations that improve its survival at high elevations. It has a set of morpho-physiological specializations, including heavier fur with longer hairs, a longer gestation period, a reduction in the number of teats and in the number of offspring per litter, and strong territoriality (Diaz et al., 1997).

Mountain Tapir (Order Perissodactyla)

The mountain tapir is known from Andean region of Colombia, Ecuador and Northern Peru, above 1400–4700 m asl. Its population is heavily fragmented, therefore leading to a genetic bottleneck effect (Downer, 1997, 2001). Also this species displays several attributes (slow reproduction rate, large home range, solitary nature) that make it particularly vulnerable (Downer, 1997). Human activities, such as hunting, farming, mining and habitat conversion are among the major conservation threats (Lizcano et al., 2002). Also there is a great concern about the effects of climate change on mountain tapir populations (Ortega-Andrade et al., 2015).

Rodents (Order Rodentia)

Rodents comprise more than half of all Neotropical mammal species (Maestri and Patterson, 2016), and occupy most terrestrial environments (Lacher et al., 2016). They are separated into two groups: "caviomorphs or sigmodontines", which have greater diversity (Patton et al., 2015; Upham and Patterson, 2015; Ojeda et al., 2015a, 2016). Previous studies showed that the Andes support high levels of species richness and turnover of rodents (Amori et al., 2013; Maestri and Patterson, 2016). Rodents encompass almost 70% of the mammals present at the Andes (**Fig. 1**A) and are the only small mammals that inhabit elevations above 4000 m. The family Cricetidae embraces almost 80% of all the Andean rodents (108 species); meanwhile the other families are represented by no >10% (**Fig. 9**A). Fifteen out of 44 genera are considered endemic to the Andean region, with >70% of their ranges constrained to this region (**Fig. 9**B). Around 50% of the species in the Andes are categorized as least concern, 15% are considered data deficient and 14% conveyed some conservation issue.

Among families, Chinchillidae constitute a high proportion of endangered species, while Caviidae and Cuniculidae contain species categorized as near threatened (**Fig. 9**C). Most families contain species for which conservation information is scarce; there are therefore categorized as data deficient. Among the family Cricetidae almost 5% of the species are considered endangered and almost 10% are considered vulnerable (**Fig. 9**C).

Caviomorph rodents radiated in the Neotropics and now occupy a wide spectrum of landscapes, elevations, and habitats here (Ojeda et al., 2016; Upham and Patterson, 2015). The Ctenomyidae and Chinchillidae are mostly distributed in temperate regions. Tuco-tucos (Ctenomyidae) have a wide distribution from southern Peru to Tierra del Fuego, and from Andean Puna to the Atlantic coast (Upham and Patterson, 2015), several species show restricted distributional ranges and some are known only from the type locality (Ojeda et al., 2016). On the other hand Chinchillas extend from the central Andes to southern Patagonia. Specifically, the genera *Chinchilla* and *Lagidim* are restricted to Altiplano and Puna environments (Valladares et al., 2014; Ojeda et al., 2015a, 2016). The main threats for Chinchilla populations are mining exploitation and commercial hunting for the fur trade (Valladares et al., 2014).

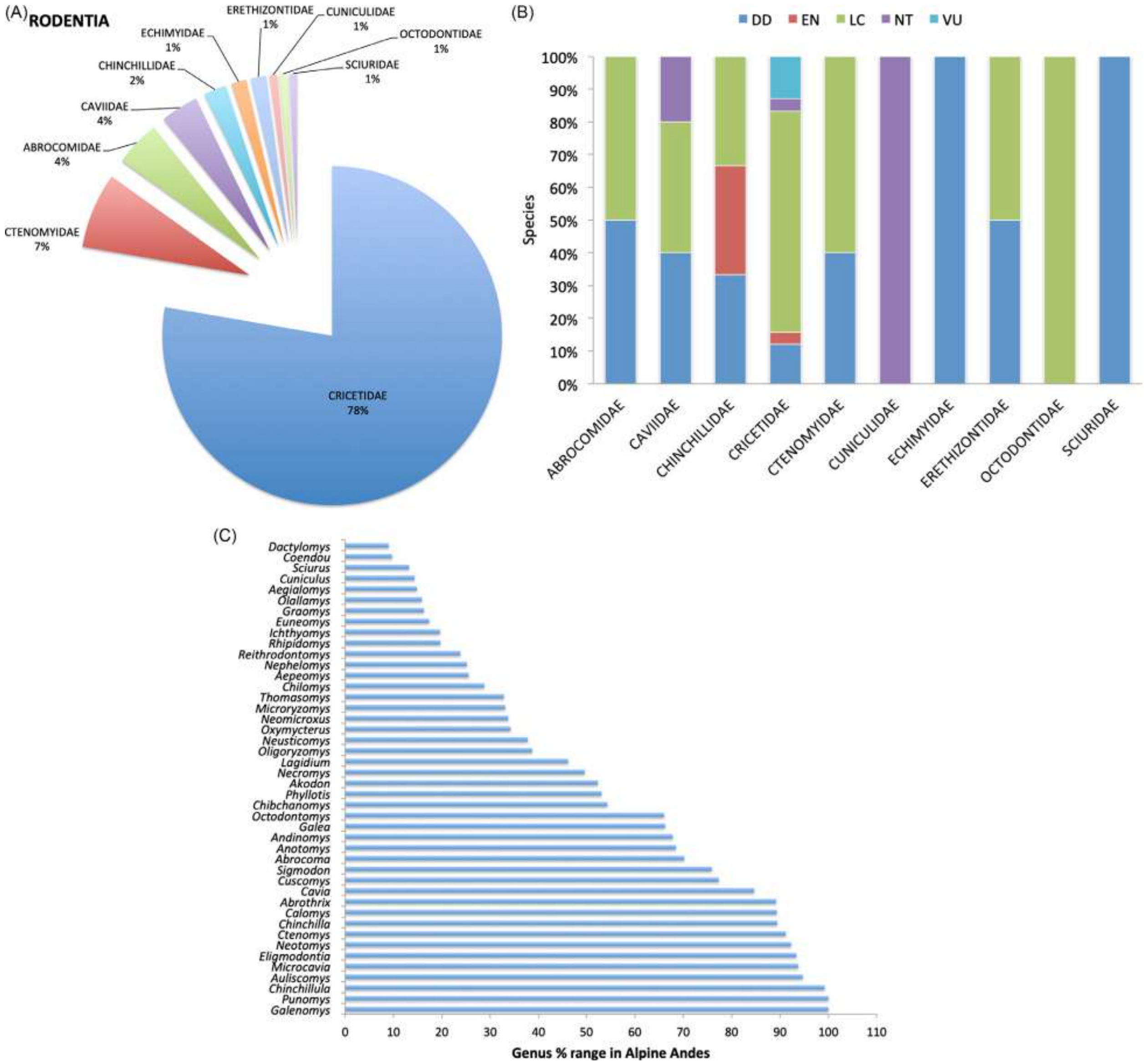

Fig. 9 (A) Percentage of High Andean rodents by family. (B) Conservation status, percentage of species in each IUCN red list category. (C) Percentage of the species range encompass along the alpine region.

The distribution patterns of the families Octodontidae and Abrocomidae extend along the arid Andes (Upham and Patterson, 2015). Among Octodontids, the mountain degu (*Octodontomys gliroides*) lives in dry Andean zones of northern Chile, Bolivia and northwest Argentina, mostly in rocky areas with herbaceous vegetation (Verzi et al., 2015). On the other hand, the chinchilla rats (Abrocomidae) show restricted and non- overlapping ranges along the southern Andes (Woods and Kilpatrick, 2005). The family Caviidae shows the broadest distribution among caviomorphs and includes most major biomes. The highest species density occurs in the dry south-central Andes, in the Cerrado and Caatinga ecoregions (Ojeda et al., 2015a).

The Echimydae, Erethizontidae and Sciuridae are mainly found in tropical forests, with high diversity along the Yungas and in Amazonia. Most species occupy arboreal habits and may reach the Alpine region marginally, mostly in the Páramos of Colombia and Venezuela (Ojeda et al., 2016; Upham and Patterson, 2015).

The geographic distribution of the family Cuniculidae extends from central Mexico to northern Argentina (Ojeda et al., 2015a). Species density is highest in the tropical Andes region (Ojeda et al., 2015a; Upham and Patterson, 2015). Only the Mountain Paca (*C. taczanowskii*) is found in the high Andes of Peru, Ecuador, Colombia, and Venezuela (Woods and Kilpatrick, 2005), between elevations of 2000 and 3500 m asl. This species is considered as near- threatened due to habitat destruction, invasive species and hunting pressure (Zapata-Ríos and Branch, 2016).

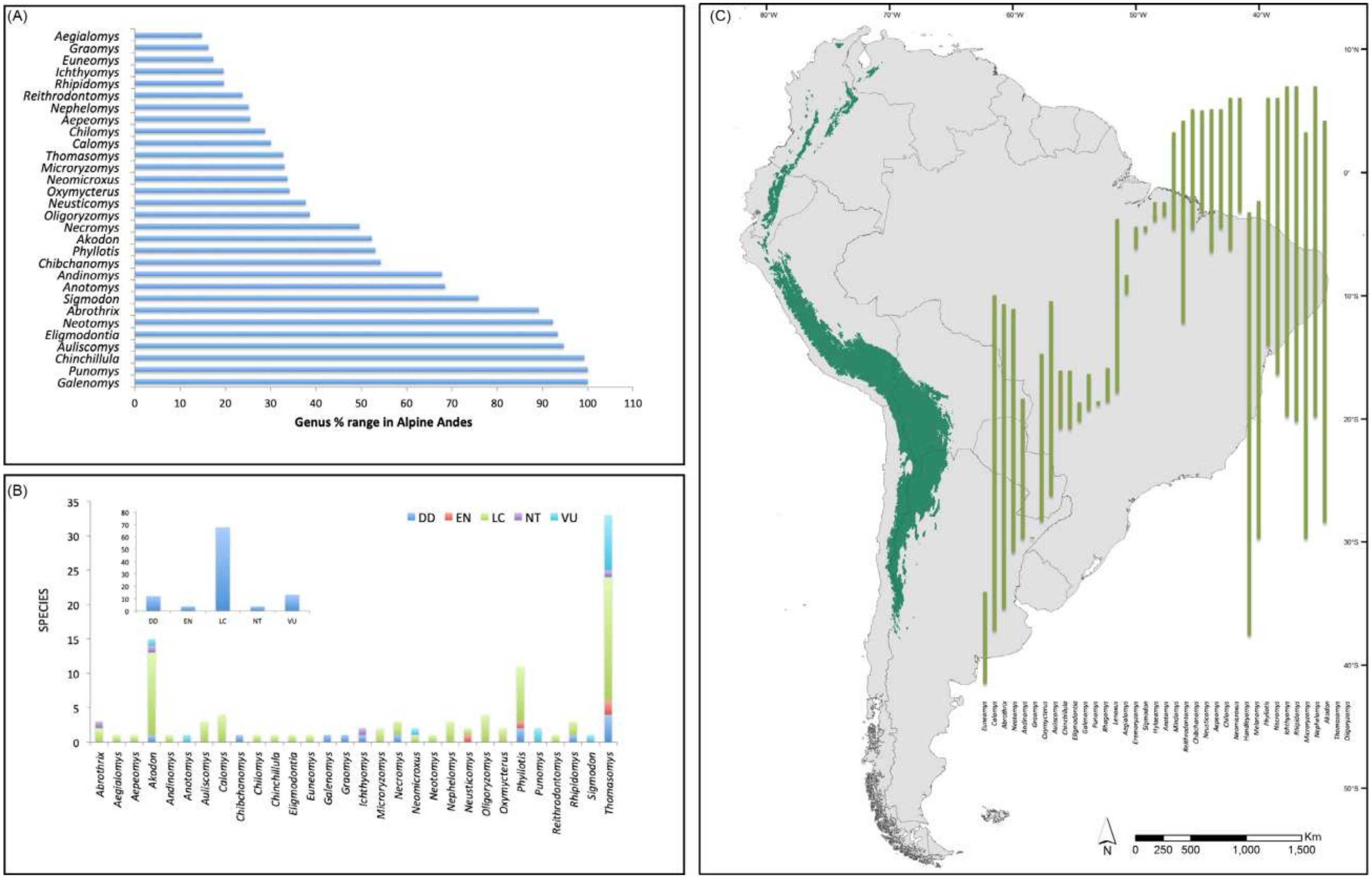

Fig. 10 Cricetidae family. (A) Percentage of the species range encompass along the alpine region. (B) Conservation status among each species and among all cricetidae. (C) Species ranges along the alpine environment.

Among cricetid rodents, some genera are mainly Andean in distribution (*Chinchillula*, *Auliscomys*, *Punomys*, among others) and others with broad distributions in other ecoregions that extend into the Andes (*Akodon*, *Oligoryzomys*, *Oxymycterus*, etc.) (Patton et al., 2015). Half of the genera present in the high Andes area have >50% of their ranges in this region (**Fig. 10**A). Almost 70% of these species are considered as least concern, while 10% are poorly known and categorized as data deficient, plus 20% that have some level of conservation issues (**Fig. 10**B).

Alpine rats and mice's ranges confirm that the Huancabamba depression separates two different groups: a northern and a southern one (**Fig. 10**C). The Central Andes was recognized as an important area for sigmodontines differentiation (Novillo and Ojeda, 2012; Maestri and Patterson, 2016; and reference therein). Therefore the Puna and the Altiplano are considered to harbor high species endemism (Ojeda et al., 2000).

Concluding Remarks

One of South-America's most vexing and polarizing challenges is how best to manage public lands established for multiple uses such as natural resource extraction, wildlife, and recreation. The intersection between energy development and biological conservation affords opportunities both to gather knowledge and to implement findings about how to mitigate impacts to wildlife, without neglecting local and regional development. Among all species registered in the Andes, 32% of rodents, 25% of ungulates and 5% of bats and carnivores can be considered endemics, with >70% of their ranges found in the Alpine region. Most of these species show adaptations to harsh climate (low temperatures and oxygen pressure) (Ostojic et al., 2002); and are habitat specialists confined to a specific habitat type (Andean cats, mountain vizcachas, vicuñas, among others).

As the footprint of human development continues to expand globally into regions that have historically supported abundant wildlife resources, there will be even more pressing needs for long-term data collection, in conjunction with baseline data, to examine changes in life history parameters and behavioral processes. Mountains are fragile environments (Diaz et al., 2003), which are strongly affected by climate change and several anthropogenic pressures (Young, 2009). Mountain regions are highly sensitive to climate change, and show above average warming, in comparison to global means during the 20th century (IPCC, 2014; Nogués-Bravo et al., 2007). Therefore, under this scenario elevational shifting of climatic belts is expected to occur, with concomitant effects on biodiversity. Species are expected to shift their distributions upslope in response to warming; however, there may no longer be appropriate habitat on mountain summits, leading to a high likelihood of Alpine species extinction (Oppenheimer et al., 2014). For example, regions of highest mammals richness (southern Paramo and the Puna/Altiplano, **Fig. 1**) will experience a temperatures rise up to 5°C (IPCC, 2014; Baez et al., 2016). This future scenario may lead to an upward shift of tree limit, reducing the alpine environment area, and constraining the suitable environment of several species. There is evidence of mountain species extinctions due to severe range contraction among endemic species (Parmesan, 2006) and that species from tropical latitudes are unlikely to evolve physiological tolerances to heat increase, being more affected by climate change (Araújo et al., 2013.). Among rodents, high Andean species show that animals from mid- and high elevations reduced their activity under high temperatures; this behavior decreases animal foraging and reproducing time, leading to fitness reduction (Sassi et al., 2015).

Conflicts between humans and wildlife occur when the interests and objectives of human activities, such as extensive and intensive livestock farming, agriculture and extractive activities do not take into account the native flora or fauna of the landscape, much less its functional diversity in a perspective of conservation of ecosystem services. Anthropogenic activities such as land change use for farming (small and large scale agriculture), oil and gas prospecting, invasive species introduction (feral dogs), and city expansion, are among the major threats to biodiversity (Zapata-Ríos and Branch, 2016; Salvador et al., 2014). Such unplanned activities represent a key challenge for society because their negative impacts can affect food security (wildlife damaging crops), the sustainability of ecosystems (over-exploitation of available resources) and biodiversity (human dimension as an agent of stress, loss of habitat and functional diversity, displacement of native species by exotic species). Thus, the sum of the effects of human activities can threaten the integrity of e ecosystems on which both biodiversity (fauna and flora) and agriculture and livestock depend, i.e. whether the species that provide key ecosystem services (nutrient cycling, pollination, etc.)

In summary Alpine environments are fragile, vulnerable and lack the required resilience to withstand future changes (Gonzalez et al., 2010). They are inhabited by cold adapted species in most cases with restrictions to migrate, or adapt to new scenarios. Therefore these regions should be a top priority when studying the effects of climate change (Dirnböck et al., 2011; Laurance et al., 2011) and among conservation actions.

Appendix: Supplementary Material

Supplementary material related to this chapter can be found online at https://doi.org/10.1016/B978-0-12-409548-9.11907-4.

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