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THE LAST 25 YEARS OF RESEARCH ON TERRESTRIAL CARNIVORE CONSERVATION IN ARGENTINA

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ABSTRACT. Twenty-seven species of terrestrial carnivores (Order Carnivora) inhabit Argentina, representing 10.0% and 38.6% of the global and Neotropical diversity of terrestrial carnivores, respectively. We evaluate the main topics of research on carnivores in Argentina over the past 25 years (1994-2018) considering the great conservation challenges the group faces. Feeding and spatial ecology, conflicts with livestock production, impacts of hunting and invasive species, and conservation genetics have been addressed for some of the more charismatic and larger-bodied carnivore species. Also, we identify thematic and taxonomic gaps and discuss what research we believe is important to deal with key conservation and management needs. Further studies are needed on topics like the ecological role of carnivores in ecosystems (including carnivores' role in rewilding projects), mitigation methods to reduce conflict, conservation status of rare or less conspicuous species, and impacts of emerging threats like climate change, disease, and expansion of feral dog populations.

RESUMEN. **Los últimos 25 años de investigación para la conservación de los carnívoros terrestres en Argentina.** Veintisiete especies de carnívoros terrestres (Orden Carnivora) habitan la Argentina, representando el 10.0% y el 38.6% de la diversidad global y neotropical de los carnívoros terrestres, respectivamente. Evaluamos los principales tópicos que han sido tema de investigación en carnívoros a lo largo de los últimos 25 años (1994-2018) en el país, considerando los grandes desafíos de conservación que enfrenta el grupo. La ecología trófica y espacial, el conflicto con la producción ganadera, los impactos de la caza y las especies invasoras, y la genética de la conservación han sido abordados para algunas de las especies de carnívoros más grandes y carismáticas. Buscamos además identificar brechas temáticas y taxonómicas y discutir qué investigaciones creemos son importantes para abordar necesidades de conservación y manejo claves. Se necesitan más estudios sobre temas como el papel ecológico de los carnívoros en los ecosistemas (incluyendo el rol de los carnívoros en proyectos de restauración), métodos de mitigación para reducir conflictos, el estado de conservación de las especies raras o menos conspicuas y los impactos de amenazas emergentes, como el cambio climático, enfermedades o la expansión de las poblaciones de perros ferales.

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RESUMO. Últimos 25 anos de pesquisa em conservação de carnívoros terrestres em Argentina. Vinte e sete espécies de carnívoros terrestres (Ordem Carnivora) habitam a Argentina, representando 10.0% e 38.6% da diversidade global e neotropical, respectivamente. Foram avaliados os principais tópicos de pesquisa sobre carnívoros na Argentina nos últimos 25 anos (1994-2018), considerando os maiores desafios de conservação que o grupo enfrenta. Ecologia alimentar e espacial, conflitos com a produção animal, impacto da caça e de espécies invasoras e genética da conservação foram abordados para algumas das maiores e mais carismáticas espécies de carnívoros. Além disso, foram identificadas lacunas temáticas e taxonômicas e discutidas quais pesquisas são consideradas importantes para lidar com as principais necessidades de conservação e manejo. São necessários mais estudos sobre tópicos como o papel ecológico dos carnívoros nos ecossistemas (incluindo o papel dos carnívoros em projetos de renaturalização de ecossistemas), métodos de mitigação para reduzir conflitos, estado de conservação de espécies raras ou menos conspícuas e impactos de ameaças emergentes, como mudanças climáticas, doenças e expansão de populações de cães selvagens.

Key words: Carnivora, conservation challenges, Neotropics, research.

Palabras clave: Carnivora, investigación, Neotrópico, retos de conservación.

Palavras chave: Carnivora, pesquisa, Neotropico, desafios de conservação.

INTRODUCTION

The Neotropical region has the largest number of described mammal species worldwide (1617; Burgin et al. 2018). Of these, 269 species make up the Order Carnivora after aquatic families Odobenidae, Otariidae and Phocidae are excluded. Twenty-seven species of terrestrial carnivores (hereafter "carnivores") inhabit Argentina (Teta et al. 2018), representing 10.0% and 38.6% of the global and Neotropical carnivore diversity, respectively (Burgin et al. 2018). The greatest diversity of native, extant carnivores in Argentina is concentrated in the Family Felidae (11 species), followed by Mustelidae (8), Canidae (5), Procyonidae (2) and Mephitidae (1) (**Table 1**).

Seven of the carnivore species present in Argentina are globally categorized as threatened by the IUCN, whereas eleven species are considered threatened at the national level (**Table 1**). Habitat loss, degradation and fragmentation, as well as harvesting are the main threats to mammals in Argentina (SAyDS & SAREM 2019). Understanding underlying causes of these threats and species' responses can guide the design of conservation actions. However, research on carnivore conservation challenges has had unequal coverage in Argentina in terms of threats, taxonomy and geography.

In this overview, we evaluate what topics have been the subject of carnivore conservation research in Argentina over the past 25 years (1994-2018). Also, we identify thematic and taxonomic gaps and discuss what research may be important to address conservation and management needs. We do not attempt to conduct an exhaustive literature review but to describe main research lines, illustrating them with relevant publications.

CONFLICTS WITH LIVESTOCK PRODUCTION

Contributions in this field focused on methods to monitor canid populations (e.g., Novaro et al. 2000a), testing for selective methods to control "problem" carnivores (Travaini et al. 2001), assessing the impacts of hunting on canid populations in ranches (Novaro 1995), or understanding perceptions and attitudes of livestock producers towards carnivores (Travaini et al. 2000). Interest in this topic has recently revived, seeking to diagnose conflicts (e.g., Guerisoli et al. 2017; Gáspero et al. 2018) or design management options that minimize livestock and carnivore mortality, including the use of guard dogs (e.g., González et al. 2012) and negative reinforcement with distasteful agents to create food aversion (Nielsen et al. 2015).

Table 1

Conservation status of terrestrial carnivores present in Argentina evaluated at global (IUCN 2018) and national (SAyDS & SAREM 2019) scales. Nomenclature follows Teta et al. (2018).

Family	Species	Common name	SAyDS & SAREM (2019)	UICN (2018)
CANIDAE	*Cerdocyon thous*	Crab-eating fox	LC	LC
	Chrysocyon brachyurus	Manned wolf	VU	NT
	Lycalopex culpaeus	Culpeo	LC	LC
	Lycalopex gymnocercus[*1]	Pampas fox	LC	LC
	Speothos venaticus	Bush dog	VU	NT
MEPHITIDAE	*Conepatus chinga*	Molina's hog nosed skunk	LC	LC
MUSTELIDAE	*Lontra felina*	Marine otter	DD	EN
	Lontra longicaudis	Neotropical river otter	NT	NT
	Lontra provocax	Southern river otter	EN	EN
	Pteronura brasiliensis	Giant otter	RE	EN
	Eira barbara	Tayra	NT	LC
	Galictis cuja	Lesser grison	LC	LC
	Galictis vittata	Greater grison	DD	LC
	Lyncodon patagonicus	Patagonian weasel	NT	LC
PROCYONIDAE	*Nasua nasua*	South American coati	LC	LC
	Procyon cancrivorus	Crab-eating raccoon	LC	LC
FELIDAE	*Herpailurus yaguoaroundi*	Jaguarundi	LC	LC
	Leopardus colocolo	Pampas cat	VU	NT
	Leopardus geoffroyi	Geoffroy's cat	LC	LC
	Leopardus guigna	Guiña	VU	VU
	Leopardus guttulus	Southern tiger cat	VU	VU
	Leopardus jacobita	Andean cat	EN	EN
	Leopardus pardalis	Ocelot	VU	LC
	Leopardus tigrinus	Northern tiger cat	VU	VU
	Leopardus wiedii	Margay	VU	NT
	Puma concolor	Puma	LC	LC
	Panthera onca	Jaguar	CR	NT

[*1] According to Teta et al. (2018), *L. griseus* is a synonym of *L. gymnocercus*.

HUMAN-MODIFIED LANDSCAPES

Ecological and demographic responses. At the community level, the effects of human-induced landscape changes on habitat use by carnivores were studied in various eco-regions (e.g., Caruso et al. 2016; Cruz et al. 2019). At the population level, the ecological (e.g., Farias & Kittlein 2008; Paviolo et al. 2018) and demographic (e.g. Novaro et al. 2005; Pereira & Novaro 2014) responses to livestock management, agriculture, deforestation, or hunting pressure were also evaluated. Studies on this topic greatly differ in their levels of

detail and in their temporal and spatial scales of application.

Hunting. Acting synergistically with habitat loss, poaching (i.e., illegal hunting) threatens several carnivores (e.g., Paviolo et al. 2016; Quiroga et al. 2016). Retaliatory killing has also been identified as a frequent source of mortality of carnivores (e.g., Funes et al. 2006; Carrera et al. 2012). In a culpeo (*Lycalopex culpaeus*) population that occurred in a landscape with interspersed sheep and cattle ranches in Patagonia, source-sink dynamics occurred as hunting to protect sheep created population sinks and culpeo protection on cattle ranches generated sources (Novaro et al. 2005). This type of dynamics may sustain other hunted carnivores in landscapes dominated by productive activities (Travaini et al. 2010). Lethal control of carnivores through state bounty systems was ineffective in reducing livestock losses (e.g., Llanos et al. 2014), possibly because source-sink dynamics leads to rapid recolonization by dispersers, suggesting the need to better understand and respond to human-carnivore interactions in productive landscapes.

Roads. Local assessments of carnivore road-kill mortalities have been conducted (e.g., Cuyckens et al. 2016; Bauni et al. 2017). However, knowledge on the extent, magnitude, and population effects of road-kill mortality throughout most of the Argentine territory is unavailable; as is the influence of age, sex, body size, activity, or diet on the probability of being killed on roads. Also, no long-term or large-scale research has focused on issues such as road characteristics or temporal and spatial factors that modulate carnivore road-kill mortalities. As a result, mitigation measures to reduce fatalities have been extremely scarce in Argentina (e.g., Varela 2015).

Exotic species. Exotic species have become new prey for native carnivores (e.g., Pia et al. 2003; Palacios et al. 2012). In southern Pampas grasslands, the availability of horse carcasses may increase the density and affect the spatial organization of Pampas foxes *Lycalopex gymnocercus* (Luengos-Vidal et al. 2012). In parts of northern Patagonia, due to hunting and competition with introduced livestock and lagomorphs, the biomass of large- and medium-sized native herbivores (such as guanacos *Lama guanicoe* and rheas *Pterocnemia pennata*) has decreased, making their representation as prey and sources of carrion in carnivore diets very low (i.e., <7%), a process termed ecological extinction (Novaro et al. 2000b). In this area, introduced lagomorphs greatly affect trophic webs, modifying the strength of predator-prey relationships and altering community dynamics (Barbar 2016). In contrast, in protected areas and abandoned ranches in southern Patagonia, where guanacos and other native prey have recovered in recent years, both native and introduced prey play important roles in carnivore diets (Zanón-Martínez et al. 2012). Similarly, in protected and remote areas of northwestern Argentina, native prey still play important roles in the diet of carnivores, but domestic and invasive species are often consumed (Walker et al. 2007; Donadio et al. 2010).

Trophic segregation appears to facilitate the coexistence between the only species of wild carnivore introduced in Argentina, the American mink *Neovison vison*, and two native ones: the lesser grison *Galictis cuja* in northwestern Patagonia (Delibes et al. 2003) and the southern river otter *Lontra provocax* in Tierra del Fuego (Gomez et al. 2010; Valenzuela et al. 2013). The recent invasion of chinook salmon in Tierra del Fuego could provide a new prey for both the southern river otter and the mink (Riccialdelli et al. 2017), with unknown consequences for the regional trophic web.

Domestic and feral dogs have been recorded as predators of native carnivores (e.g., Lucherini & Merino 2008; Pereira et al. 2010). Predation of native carnivores by dogs is probably widespread in Argentina, the country with the largest number of dogs per capita in the world (Mestel 2017), although events are likely underreported in the scientific literature (authors, op. cit.). In addition to killing and displacing native carnivores, free-ranging dogs frequently attack livestock and can exacerbate conflicts between native carnivores and people

(A. Schiavini, pers. com.; Montecino-Latorre & San Martin 2018).

Pathogens of domestic cats and dogs that are widely present in rural areas (i.e., canine distemper virus, canine parvovirus) are potential threats to native carnivores (e.g., Martino et al. 2004; Uhart et al. 2012). Despite the importance of this process, infection spillover from domestic to native carnivores has been poorly studied in Argentina. Antibody titers for canine distemper virus and canine parvovirus were also found in American mink in southern Patagonia, although the epidemiological importance of this finding is poorly understood (Martino et al. 2017).

TROPHIC CASCADES

Despite the importance of understanding and protecting the role of predation in ecosystems (Estes et al. 2011), few studies have been conducted on community-level trophic cascades. In the southern Puna, vicunas *Vicugna vicugna* avoid canyons with high risk of predation by pumas *Puma concolor*, leading to increased plant complexity in canyons (Donadio & Buskirk 2016). Similarly, the risk of predation by pumas may have a significant impact on guanaco population fitness, affecting forage consumption and habitat selection (Marino 2010) by this dominant native herbivore of the steppe and Monte. In northernmost Patagonian steppe pumas do not move seasonally following migratory guanacos, their preferred prey (Gelin et al. 2017). Predictions about significant impacts on prey populations due to predation by pumas and culpeos based on indirect assessments of kill rates (Novaro & Walker 2005) require further testing.

PREDICTIVE MODELS

The distribution of some carnivores, including the poorly known bush dog *Speothos venaticus* (DeMatteo & Loiselle 2008), Andean cat *Leopardus jacobita* (Marino et al. 2011), and Patagonian weasel *Lyncodon patagonicus* (Schiaffini et al. 2013) have been analyzed considering climatic, environmental and human-related variables to infer ecological requirements and predict geographic and climatic ranges. Conservation models for carnivore populations facing different threats in Argentina were also developed, including a landscape specifically designed for jaguar (*Panthera onca*) conservation and management in the Atlantic Forest (De Angelo et al. 2013), an analysis of the possible impacts of climate change on the potential distribution and viability of some carnivore populations (e.g., Canepuccia et al. 2008; Torres et al. 2013; Cuyckens et al. 2015), and the identification of corridors to avoid jaguar population fragmentation (e.g., Martinez-Pardo et al. 2017).

GENETICS

Studies using molecular genetic tools in Argentina during the last 25 years have applications in conservation, especially those characterizing taxonomic units and determining Evolutionary Significant Units (ESUs) and Management Units (MUs), the genetic base for conservation plans. Based on genetic studies of the Argentinian populations of the maned wolf, only one MU was recognized (Raimondi 2013). Moreover, the two maned wolf population sources proposed by Pautasso (2009) ("Bajos Submeridionales" and "Bañados del Río Dulce/ Laguna Mar Chiquita") showed little genetic variation, pointing to another population ("Iberá") as the most variable and thus most plausible stronghold for the species in Argentina (Raimondi 2013).

The once continuous historical distribution of the jaguar in Argentina has been reduced to three, apparently separate populations (Yungas, Chaco and Atlantic Forest eco-regions). The jaguar population of the Atlantic Forest of Argentina has already lost genetic diversity but still has higher allelic richness than other smaller populations of the Brazilian Atlantic Forest, from which it is currently isolated and has differentiated by genetic drift rather than adaptive evolution (Haag et al. 2010). A preliminary comparison of the three Argentinian wild populations with captive jaguars in Argentinian zoos (Font 2016; P. Mirol, unpublished) indicated very similar genetic variability in both

groups, amongst the lowest estimated for the species. The low genetic effective size of the captive population (6.8), much lower than its number of individuals (37), and the significant genetic differentiation among the three wild populations (P. Mirol, unpublished), suggest the urgent establishment of corridors connecting these populations in northern Argentina to avoid increasing genetic loss and potential fitness reduction.

Lower genetic variability and higher relatedness in comparison with Brazilian populations, as well as a positive association between habitat quality and heterozygosity, were found in Neotropical river otters *Lontra longicaudis* inhabiting an area of high human impact (Trigila et al. 2015). For southern river otters in Patagonia, two subpopulations deserving conservation attention were postulated, with one of them appearing not to have suffered a human-induced population bottleneck of the sort experienced by other otter species (Centrón et al. 2008).

The rare Andean cat showed extremely low mitochondrial and nuclear genetic diversity throughout its range (Cossios et al. 2012). The geographic structure of this cat's genetic diversity was strong, but differed from that of other Andean species, something perhaps explained by isolation in high-altitude "islands" and use of corridors inaccessible to other species. Cossios et al. recognized two ESUs; the southern ESU, at lower elevation in northwestern Patagonia, may be highly endangered due to its smaller range, high conflict with livestock producers (Novaro et al. 2010), and increasing impact from the largest hydrocarbon operation in Argentina (Walker et al. 2013).

Scat detection by trained dogs and posterior genetic analyses allowed species identification and analyses of genetic diversity and habitat use by five carnivore species (bush dogs, jaguars, pumas, ocelots *Leopardus pardalis* and southern tiger cats *L. guttulus*) in the Atlantic Forest of Argentina (DeMatteo et al. 2014a; 2014b). Results for the endangered bush dog suggested more tolerance to disturbed habitat than previously thought, but incipient genetic differentiation and possible dispersal limitation between two portions of the Misiones Green Corridor (DeMatteo et al. 2014b).

WHAT NEXT?

We identify five broad research topics and tools that we believe could help carnivore conservation significantly in the near future in Argentina:

Under-studied species. Almost all Argentine carnivore species have been the subject of at least one study with conservation implications, with the exception of very rare (and possibly locally extinct) giant otters *Pteronura brasiliensis*, marine otters *Lontra felina*, and greater grisons *Galictis vittata*. Other species have a very poor representation in terms of research (e.g., Patagonian weasel, tayra *Eira barbara*). Basic understanding of distributions, biological needs, and threats of these poorly studied species is necessary to determine potential conservation actions. Additionally, periodic assessments of species knowledge and conservation priorities (e.g., Lucherini et al. 2004) are essential to update research needs.

Human-wildlife conflicts. Human-wildlife conflicts here addressed are widespread in productive lands of Argentina, which encompass >50% of its territory (Trading Economics 2019). In addition, interactions among threats may quickly escalate in local or regional importance in the near future, deserving special attention. For example, fracking will likely exacerbate the impact of traditional hydrocarbon extraction and desertification, causing habitat degradation and threatening water resources affecting regions and species beyond the Patagonian Andean cat (Walker et al. 2013). Human–carnivore conflicts will likely increase in Argentina due to increasing demand for agricultural products and consequent land-use change, so novel interventions that promote coexistence based on robust scientific evidence and applicable to local socio-economic conditions are urgently needed. A thorough understanding of the impacts of the overall and emerging threats to carnivore populations will allow stakeholders to do more

than just respond to crises, instead establishing pre-emptive management actions based on the needs of carnivores and other wildlife.

Climate change. Climate is rapidly changing worldwide (Barros et al. 2015), exacerbating other threats and triggering new challenges for conservation. Understanding the spatial structure, dynamics and trends of carnivore populations and their ecosystem-level interactions is key to predicting the consequences of climate change, identifying practical measures to reduce and adapt to anticipated effects, and improving our capacity to conserve carnivores (Mawdsley et al. 2009). For example, the development of connectivity models taking into account climate change and landscape change projections, like agriculture expansion, will improve the design of corridors to minimize the effects of fragmentation on carnivores (Correa-Ayram et al. 2016). Another possible interaction with climate change is the exacerbation of carnivore-livestock conflicts. As forage availability declines during droughts or floods and livestock herds become nutritionally stressed, livestock can become more vulnerable to predation. Thus, we must increase our ability to predict and adapt to these events, as well as have new effective tools to protect livestock.

Citizen science / Volunteer work. Citizen science and participatory volunteer networks are becoming increasingly common to assist carnivore research and monitoring activities (Silvertown 2012). For example, when testing tools for carnivore conflict mitigation, active and continued engagement of local people has been crucial, as demonstrated in trials with livestock-guard dogs in Patagonia (González et al. 2012). The jaguar and puma populations of the Upper Paraná Atlantic Forest ecoregion of Argentina, Brazil and Paraguay were mapped and monitored with a volunteer network comprising > 100 volunteers (De Angelo et al. 2011). A similar initiative is currently being implemented in the Argentine Chaco to monitor jaguars (V. Quiroga, pers. comm.). Citizen science and conservation initiatives will become more common in Argentina and the Neotropics, particularly with charismatic species that attract public attention, as new technologies facilitate communication, data acquisition and processing (Silvertown 2012).

Rewilding. Several carnivore species have become regionally or locally extinct, the distributions of some carnivores have been drastically reduced, and their native prey have been depleted. For example, the jaguar currently occupies less than 5% of its original area (Di Bitetti et al. 2016) and it is considered ecologically extinct in the Chaco (Quiroga et al. 2014). The restoration of ecosystems through keystone species reintroductions, referred to as rewilding, is an increasingly used technique to restore ecosystem processes and services (Svenning et al. 2016). A large rewilding initiative is taking place in Argentina, in the Iberá National Park (Root-Bernstein et al. 2017). Two critically endangered large carnivores, the jaguar and the giant otter, are targets of reintroduction efforts, together with other mammal and bird species (Zamboni et al. 2017). Research and monitoring of ecological and genetic aspects of reintroduced populations and their communities, as well as social attitudes toward this rewilding program should provide the foundations for success of future rewilding projects in Latin America (Root-Bernstein et al. 2017).

Innovative strategies are required to prevent future loss of carnivore habitats and populations, and to mitigate human-carnivore conflict in the face of expanding human demands, land-use intensification, climate change, and exotic species introductions. Addressing the great conservation challenges that carnivores face through well-planned research and appropriate management actions will help secure the diversity and valuable ecological roles of carnivores in Argentina.

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