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REVIEW

Understanding trends in biological invasions by introduced mammals in southern South America: a review of research and management

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ABSTRACT

1. Invasive introduced mammals (IIMs) have ecological and social dimensions that require holistic research to integrate academic disciplines with basic and applied sciences.
2. We assessed current knowledge of IIMs to determine trends in their study and management in southern South America.
3. A keyword search was used to select indexed papers in the Web of Science. These were reviewed to assess each study's objective, methodology, country, publication year, and taxa. Unpublished 'grey' literature was added to evaluate further each species' native range, year of introduction, the reason for its introduction, its distribution, dispersal pathways, impacts, and management.
4. Most of the 190 peer-reviewed publications were focused on autecology and impacts of IIMs; less than 4% addressed management or social topics. Twenty-three IIMs have been documented in the study area. The southern Magellanic subpolar forest was the most invaded ecoregion (17 spp.), and the most studied orders, from 440 records in 190 papers, were Artiodactyla (35%) and Rodentia (28%). Together, livestock and commensals brought during early European colonisation constituted 44% of this assemblage, but hunting was the major reason behind the introduction of IIMs (30%).
5. To enhance policies and institutional frameworks pertaining to biological invasions, we highlight the importance of: 1) recognising the presence and spread of IIMs in 'pristine' or protected areas; 2) improving controls to prevent new introductions and escapes; 3) including social and cultural aspects of biological invasions in research and management plans; 4) reinforcing hunting regulations; 5) establishing long-term programmes to monitor distribution and dispersion; 6) creating mechanisms for scientists and managers to co-produce research and policy programmes oriented towards applied issues; 7) developing pilot management projects in critical areas; 8) achieving societal involvement in management programmes to ensure public acceptance; and 9) developing prioritisation tools, as resources needed to manage IIMs are often limited.

INTRODUCTION

Globally, the list of human-introduced species increases, as does the number that become invasive and have significant ecological, economic, and cultural effects (Mooney & Hobbs 2000). Partially due to the global scale of the biological invasion phenomenon, some scholars have called for us to recognise that the world is now largely composed of 'novel ecosystems' with unprecedented species assemblages (Hobbs et al. 2006) that require new approaches to conservation (Kareiva & Marvier 2012). In this context, a vigorous debate has been waged concerning the overall utility of the 'invasion' metaphor and approach (Larson 2005, Davis et al. 2011). However, Simberloff et al. (2013) pointed out that invasion biology is as predictive as any sub-discipline of ecology, and that our ability to resolve problems related to invasive species (not all of which are introduced) has significantly improved. In this context, an important objective of invasion biology today is to relate this ostensibly biological process more closely to its social, political, cultural, and applied aspects; this would make invasion biology both a more predictive science and more useful in conservation issues (Estévez et al. 2015). We put forward that achieving this goal requires us to generate updated and organised information that is available to both scientists and managers.

Like in the rest of the world, biological invasions pose a serious threat to biodiversity, ecosystems, and human endeavours in South America (Rodriguez 2001, Vilà et al. 2011). Despite being relatively remote, even the continent's southern tip experiences this globalised phenomenon (Vázquez & Aragón 2002). Many introduced species trace their origins to the earliest European colonisation of the Americas (Ziller et al. 2005) and were brought for diverse reasons: as livestock, companion animals, commensals, or for sport hunting (Long 2003). Invasive introduced mammals (IIMs) are of particular concern for conservation and require the attention of both scientists and managers, because as a group they are known to be more invasive than other vertebrates, such as birds (Jeschke 2008). As such, they are a particularly important driver of loss and homogenisation in biodiversity (Courchamp et al. 2003) and of alteration to ecosystem processes (Ehrenfeld 2010). Their socio-cultural interactions are also especially strong (Pfeiffer & Voeks 2008).

There have been several reviews of IIMs at the country level within southern South America, in Argentina (Navas 1987, Novillo & Ojeda 2008, Merino et al. 2009), Chile (Jaksic 1998, Jaksic et al. 2002, Iriarte et al. 2005), and Uruguay (Pereira-Garbero et al. 2011). A systematic analysis of IIMs is lacking for this broader region and is needed in order to improve our approximation of meaningful biogeographic units of study. Such a systematic approach also will allow a better understanding of introduction history, the current assemblage, and the distribution and impacts of IIMs, knowledge that is required to design effective management strategies (Genovesi 2005). Furthermore, determining variations in trends in these variables between taxa could help clarify more ecologically and socially meaningful factors that may help us to explain the patterns and processes of biological invasions and move beyond the description of case studies or quantification of impacts (Brown & Sax 2004).

Here, we review the academic literature on IIMs in southern South America, in order to determine trends and patterns in the amount and type of research conducted to date. In addition, we summarise and update information, from both peer-reviewed and unpublished 'grey' literature sources, to establish the origin, reasons for introduction, distribution, impacts, and management of each IIM species. Conducting such an assessment allowed us to synthesise current knowledge and to detect deficiencies or gaps that can be attended to in future work. By integrating a bibliometric evaluation of the literature with a summary of information regarding actions taken in the field concerning these species, this exercise can help improve the link between basic research and applied management.

METHODS

The literature search covered the years 1974 to June 2015, and was conducted to update basic information on IIMs in southern South America (Argentina, Chile, and Uruguay). Peer-reviewed journal papers were searched for in the Web of Science, which included Biological Abstracts, BIOSIS Citation IndexSM, Current Contents Connect, Data Citation IndexSM, Derwent Innovations IndexSM, KCI – Korean Journal Database, MEDLINE, SciELO Citation Index, and Zoological Record data bases, using the keywords 'mammal', 'invas*/alien*/exotic*/non-native/non-indigenous', and the topic/address 'Argentina/Chile/Uruguay'. The results were filtered for journals in the following categories: Environmental Science & Ecology, Zoology, Marine & Freshwater Biology, Agriculture, Entomology, Forestry, Plant Sciences, Veterinary Sciences and Biodiversity Conservation. Subsequently, we checked the references cited in the papers we found. The unpublished 'grey' literature (technical reports, theses, summaries, non-scientific books, etc.) was searched in different online data bases (e.g. http://www.sib.gov.ar) or assessed from relevant institutions from the three countries, such as universities, national park offices, environmental agencies, etc.

For the purposes of this review, we included only mainland territories and immediately adjacent islands, excluding data from Antarctica and oceanic islands such as Malvinas, South Georgia, South Sandwich, Juan Fernández, and Easter Islands (Fig. 1). Furthermore, we only considered those

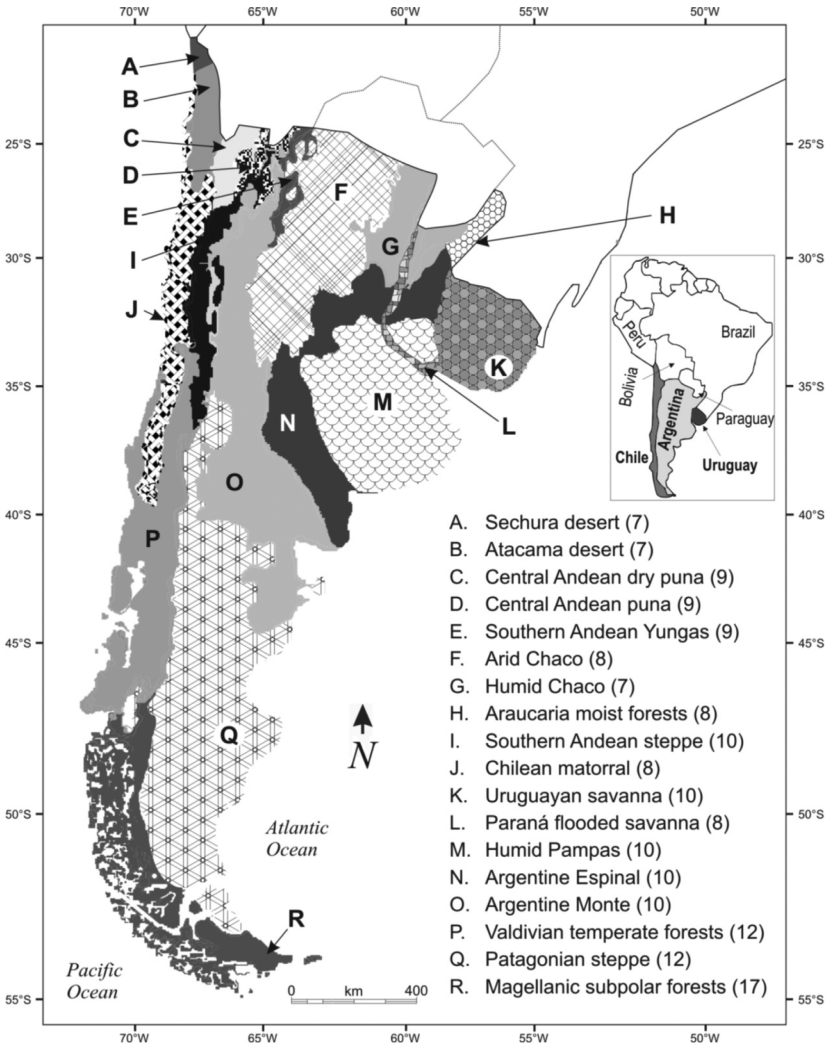

Fig. 1. Map of southern South America (Argentina, Chile and Uruguay) comprised of 18 biogeographic units. The number of invasive introduced mammalian species in each ecoregion is indicated in parentheses (adapted from Fund & McGinley 2013, Fund 2014, Hogan 2013).

species that were both introduced by humans and are invasive (i.e. have expanding wild populations that are affecting other species or humans), including those native species that have been moved by humans within the region to new areas. We did not include introduced mammalian species currently found only in fenced game reserves, such as white-tailed deer *Odocoileus virginianus*, elk *Cervus canadensis*, Père David's deer *Elaphurus davidianus*, Barbary sheep *Ammotragus lervia*, wisent *Bison bonasus*, chamois *Rupicapra rupicapra*, European mouflon *Ovis orientalis musimon*, Alpine ibex *Capra ibex*, and Dall's sheep *Ovis dalli*. However, these species that have been brought to the region have a high probability of naturalising and becoming invasive, if (or when) individuals escape from their confinements.

Modifying the rubric in Quiroz et al. (2009), we assessed the objective of each publication as: 1) autecology; 2) impacts; 3) management; 4) patterns (or distributions); 5) presence/absence (or inventories); 6) processes (or mechanisms); or 7) social. We also characterised the level of biological organisation investigated in each study as genetic, population, community, or ecosystem, and each paper was classified as using an experimental, review, field sampling, or modelling approach. Furthermore, we categorised the stage of invasion being evaluated in each case (introduction, naturalisation, and invasion). Then, the studies were organised according to country (Argentina, Chile, Uruguay), year of publication, and by the species or taxonomic group studied.

Only peer-reviewed publications were used to determine trends in research, specifically by assessing the objectives, approaches, taxa, and biological level of organisation of studies based on the percentage of total published research. However, the entire body of scholarship, including 'grey' literature, was used to describe each IIM in terms of its: 1) native range, year of introduction, and reason for intro-

duction (accidental, escape from captivity, sport hunting, as livestock, for biological control, as a pet, for aesthetic reasons, for the fur industry); 2) current distribution per country and ecoregion (localised-restricted populations, regionally abundant populations, or widespread extensive populations) and dispersal pathways (natural expansion from introductions in other places, intentional or accidental transport by humans); 3) documented or known impacts; and 4) former or current management actions.

RESULTS

Trends in publications on invasive introduced mammals

The Web of Science search yielded 190 publications on IIMs in southern South America (Appendix S1). Fifty-nine per cent ($n = 113$) of the studies were conducted in Argentina, 31% ($n = 58$) in Chile, only 2% ($n = 3$) in Uruguay and finally 8% was conducted in more than one country. Research on IIMs has increased exponentially since the first publication in 1977; 83% of all papers were published in the last decade (Fig. 2). Among the 440 records in 190 papers, the most studied orders were Artiodactyla (35%), Rodentia (28%), Lagomorpha (16%), and Carnivora (15%), followed by Perissodactyla (5%) and Cingulata (0.9%). The most studied species and taxonomic groups were livestock (*Bos taurus*, *Equus asinus*, *Equus ferus caballus*, *Ovis aries*, *Capra hircus*), the North American beaver *Castor canadensis*, mice and rats (*Mus* spp. and *Rattus* spp.), the American mink *Neovison vison*, the red deer *Cervus elaphus*, the wild boar *Sus scrofa*, the European rabbit *Oryctolagus cuniculus*, and the European hare *Lepus europaeus* (Table 1).

Most research (82% of the 190 papers) has been focused on the invasion stage of IIMs, and relatively few publications were conducted during naturalisation (12%) and introduction (6%). Research on IIM has been focused principally on their autecology (29% of the 190 papers) and impacts (28%; Fig. 3). To a lesser extent, publications were about ecological processes and species inventories (each 14%), and distribution and assemblage patterns (8%). To date, applied management (4%) and social topics (3%) have been the subject of the smallest amount of research. Furthermore, while management-focused research made up a very small percentage of the total, the majority of these few studies (82% of the 23 studies) were reviews, rather than empirical or experimental research (Fig. 3). Most researchers used field sampling as their methodology (74% of the 190 papers); only 1.5% utilised experimental approaches. Finally, the majority of research was conducted at the community level (47% of papers); population studies constituted close second place (42%). Only a few studies were carried out using an ecosystem approach (10%) or investigated the genetics of invasion (2%).

Trends in mammal invasions in southern South America

In this review we documented 23 IIM species in southern South America (Table 2). Many of these species have been shown to have severe effects on ecological, economic, and cultural aspects of the region (see Appendix S2 for details on each species: introduction history, distribution, pathways, impacts, and management). Argentina has all the introduced fauna reported in the literature, while Chile had 83% (19 species) and Uruguay 44% (10 species) of this assemblage.

The origins of these IIMs are diverse; almost half are native to Asia (48% of the 23 species), but Europe and North America also contributed (26% and 13% of the species, respectively). Native species translocated to new locations within the study area accounted for 9% of the

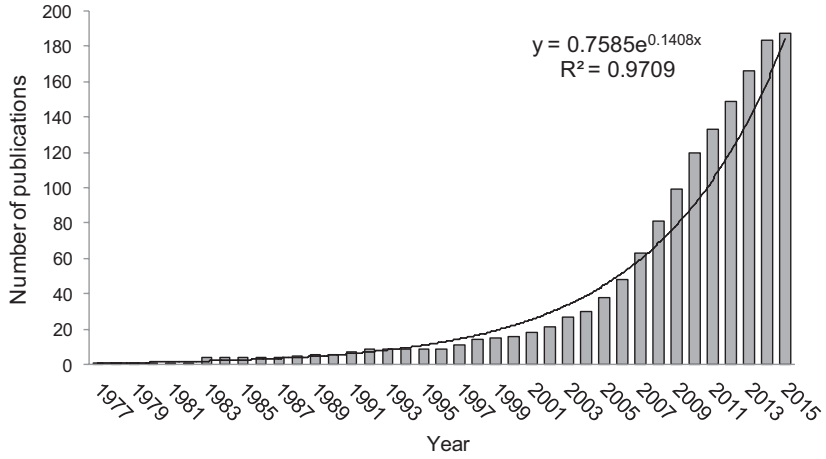

Fig. 2. The number of publications, plotted cumulatively, on invasive introduced mammals in southern South America has increased exponentially since the first publication in 1977 until 2015 ($n = 190$).

Table 1. Peer-reviewed publications on invasive introduced mammals in southern South America, organised by countries and species or groups. Columns indicate the number of times each species or group is covered in one of the 190 papers (published in 1974–2015). Each paper can cover more than one species/group and country. Therefore, column totals are >190. Percentages are calculated from the total number of items covered (440)

Species or group	Argentina #	Chile #	Uruguay #	Total #	Total %
Livestock (*Bos taurus, Equus asinus*, *Equus ferus caballus*, *Ovis aries*, *Capra hircus*)	55	21	1	77	18
North American beaver *Castor canadiensis*	24	32	0	56	13
Mice and rats (*Mus musculus*, *Rattus norvegicus*, *Rattus rattus*)	19	27	3	49	11
Red deer *Cervus elaphus*	30	13	0	43	10
American mink *Neovison vison*	16	21	1	38	9
European rabbit *Oryctolagus cuniculus*	15	19	1	35	8
Wild boar *Sus scrofa*	24	10	1	35	8
European hare *Lepus europaeus*	23	9	2	34	8
Fallow deer *Dama dama*	14	4	1	19	4
Pets (*Canis lupus familiaris*, *Felis silvestris catus*)	7	9	0	16	4
Pallas's squirrel *Callosciurus erythraeus*	11	0	0	11	2
South American grey fox *Pseudalopex griseus*	4	5	0	9	2
Muskrat *Ondatra zibethica*	3	5	0	8	2
Chital *Axis axis*	3	0	1	4	<1
Large hairy armadillo *Chaetophractus villosus*	2	2	0	4	<1
Blackbuck *Antilope cervicapra*	2	0	0	2	<1
Total	*252*	*177*	*11*	*440*	*100*

assemblage. Only one IIM came from Africa; none was recorded from Oceania (Table 2). Forty-three per cent of the 23 mammalian species were imported to southern South America during the first half of the 16th century, 30% were brought during the late 19th century and early 20th century. The remaining species ($n = 6$) were introduced in the mid- to late-20th century. The red-bellied squirrel *Callosciurus erythraeus* (1970) and the large hairy armadillo *Chaetophractus villosus* (1982) were the most recent mammalian introductions recorded for the region.

With respect to the reasons for introduction, we found that the current IIMs were originally brought to southern South America for hunting (for food or sport; 30% of the species), as livestock (22%), for fur (13%), accidentally (13%), as pets (9%), and for aesthetic purposes (9%). Only the South American grey fox *Pseudalopex griseus* was introduced as a biological control agent for invasive European rabbits on Tierra del Fuego Island; the control was unsuccessful, but the fox became invasive. Together, feral domestic species account for 35% of the IIMs in southern South America.

The most invaded ecoregions in southern South America are the Magellanic subpolar forest, with 17 IIMs, and the Valdivian temperate forest and Patagonian steppe, with 12 species each. The Sechura Desert, Atacama Desert, and

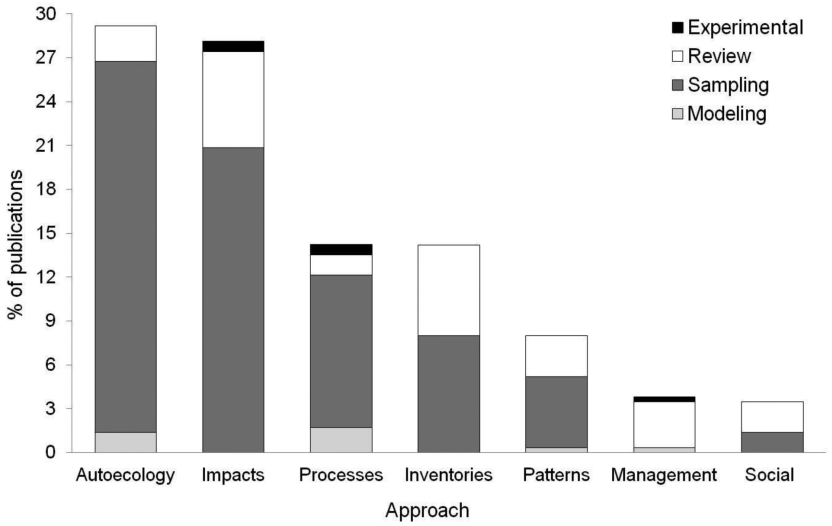

Fig. 3. Percentage of 190 peer-reviewed publications about invasive introduced mammals in southern South America, organised by research approach (bars) and methodological approach (shading within bars). Each paper could have more than one approach or technique.

Table 2. The invasive introduced mammal assemblage in southern South America, indicating species presence per country (Arg = Argentina, Ch = Chile, Ur = Uruguay; × = present), reasons for introduction, origin (Af = Africa, As = Asia, E = Europe, N = North America, S = South America) and management efforts (F = former, C = current)

Scientific name	Common name	Year	Presence			Reason for introduction	Origin	Management
			Arg	Ch	Ur			
Antilope cervicapra	Blackbuck	1906–1912	×			Hunting	As	Localised, systematic (C)
Axis axis	Chital	1906	×		×	Hunting	As	Localised, systematic (C)
Bos taurus	Cattle	1500s	×	×		Livestock	As	No information
Capra hircus	Goat	1500s	×	×	×	Livestock	As	No information
Cervus elaphus	Red deer	1906	×	×		Hunting	E, As	Localised, systematic (C)
Dama dama	Fallow deer	1887	×	×	×	Hunting	E, As	Localised, unsystematic (C)
Ovis aries	Sheep	1500s	×	×		Livestock	As	No information
Sus scrofa	Wild boar	1904–1906	×	×	×	Hunting	E, As	Localised, systematic (C)
Canis lupus familiaris	Dog	1500s	×	×	×	Pet	As	Localised, unsystematic (C)
Felis silvestris catus	Cat	1500s	×	×	×	Pet	As	No information
Neovison vison	American mink	1936–1938	×	×		Fur	N	Localised, unsystematic (C)
Pseudalopex griseus	South American grey fox	1951	×	×		Biocontrol	S	Localised, unsystematic (C)
Chaetophractus villosus	Large hairy armadillo	1982	×	×		Aesthetic/Food	S	No information
Lepus europaeus	European hare	1880s	×	×	×	Hunting	E	No information
Oryctolagus cuniculus	European rabbit	1884	×	×		Hunting	E	Hunting (F), trapping (F), myxomatosis (F), biological control (F)
Equus asinus	Donkey	1500s	×			Livestock	Af	Localised, unsystematic (F)
Equus ferus caballus	Feral horse	1500s	×	×		Livestock	E, As	No information
Callosciurus erythraeus	Pallas' squirrel	1970	×			Aesthetic	As	No information
Castor canadensis	North American beaver	1946	×	×		Fur	N	Bi-national plan Argentina-Chile (C)*
Mus musculus	House mouse	1500s	×	×	×	Accidental	As	No information
Ondatra zibethica	Muskrat	1948	×	×		Fur	N	Localised, unsystematic (F)
Rattus norvegicus	Brown rat	1500s	×	×	×	Accidental	As	No information
Rattus rattus	Black rat	1500s	×	×	×	Accidental	As	No information
		Total	**23**	**19**	**10**			

*In development and not currently in practice, but two Global Environmental Facility grants have been awarded to Chile and Argentina to execute pilot eradication projects.

Humid Chaco are the ecoregions with the lowest number of IIM (seven each; Fig. 1). We found that rodents, lagomorphs, and feral domestic pets have invaded all ecoregions in the study area (18), and conversely, blackbuck *Antilope cervicapra*, muskrats *Ondatra zibethica*, goats *Capra hircus*, sheep *Ovis aries*, and large hairy armadillos to date are only invasive in one ecoregion each. This last species, together with the South American grey fox, is native to the rest of southern South America and has been introduced to the Tierra del Fuego Island (Valenzuela et al. 2014).

We discovered only one formal, regional management effort relating to an IIM: Argentina and Chile have signed a binational agreement to attempt the eradication of the North American beaver (Table 2). However, due to the long political and institutional time-scale required to apply this plan effectively, only smaller, local actions have been carried out so far (e.g. Sanguinetti et al. 2014). On the other hand, 44% of the 23 IIM species, including American mink, red deer and wild boar, have been managed through local control efforts in small, specific areas where the species have become a particularly serious problem (e.g. on ranches or farms) or where they come into conflict with conservation initiatives (e.g. national parks, private conservation areas).

DISCUSSION

Understanding past introductions, avoiding future ones

While the 23 IIMs documented in this study only represent <6% of the total mammal assemblage in the study area (in terms of numbers of species; Ojeda et al. 2002), they constitute an important component of the ecological and social systems in southern South America (see Appendix S2). Furthermore, the number of introduced species is greater than given in previous reports, including data bases used in global biogeographic studies. For instance, Sax (2001) analysed the number of naturalised introduced mammals along a

latitudinal gradient in South America, determining that from 25 to 55°S, species richness decreased from 12 to 1. We found the opposite trend; the number of species increased to a maximum in the far south. This finding further highlights the need to conduct review and synthesis efforts to obtain high-quality information for present and future studies determining underlying patterns and processes.

As expected, mammal introductions in southern South America have a long history; the first records date back more than five centuries. While many introductions were associated with the early European colonial period, we found that the 1940s and 1950s were also a time when many non-native furbearers were brought to the region. Overall, an historical understanding of species introductions demonstrates how they have been driven largely by dominant social imaginaries (*sensu* Castoriadis 1993) that have existed and in some cases still exist, whereby native species are either less known or less valued than those brought from other parts of the world to 'improve' local ecosystems (Anderson & Valenzuela 2014). In particular, the introduction of furbearers in the 1940s to Tierra del Fuego was clearly a part of national and regional development models promoted by the Argentine government and communicated via propagandistic newsreels (Anonymous 1946). Therefore, this overarching conceptual framework helps to contextualise the reasons for mammal introductions in southern South America, which were related to their social values, particularly economic (e.g. as food and livestock) and also for hunting (for sport or food), which may be contrary to ecological values that call for the control of such invasive species (Flueck et al. 2003, Speziale et al. 2012). For example, European rabbits and hares have been declared pests in Chile, but hunting them is a lucrative business and an important social activity (Iriarte et al. 2005). Furthermore, the red-bellied squirrel in Argentina highlights how a charismatic species can cause emotional reactions in members of society, regardless of the negative impacts it may have on native wildlife or productive activities (Guichón et al. 2005).

Recognising the gap between social and ecological values and attitudes towards these species reinforces the need to develop not only integrated research, but also regulations and legislation that bring into line the potential cultural and economic use of species introductions with their ecological costs when these species become invasive. It could also help explain why, to this day, new hunting reserves are being authorised and established in the area, despite hunting being a principal reason for the introduction of the IIM reviewed here. Indeed, in addition to the species recorded in this study, there is a list of introduced mammals in captivity, mainly in fenced game reserves, that is even greater. These species could escape from their enclosures, establish wild populations, and eventually became invasive; this has already occurred with the wild boar and the red deer, which are now distributed throughout much of the region (Flueck et al. 2003, Ballari et al. 2015). For this reason, Flueck (2010) has called for caution regarding the introduction of the Himalayan tahr *Hemitragus jemlahicus* to Argentina, and similarly, Valenzuela et al. (2014) alerted to the danger of red deer kept on a ranch on the Chilean side of Tierra del Fuego Island.

Currently, social perceptions of introduced species have changed somewhat, but not in all social groups. In southern Patagonia, it was found that there is still a gap between scientists and managers on the one hand, who consider introduced species a major threat, and members of the broader community on the other, who do not concur with this belief (Zagarola et al. 2014). In this context, our findings on the current trends in research on IIMs should help orient more relevant research. Overall, the study of IIMs is increasing exponentially, but at the same time, the social and political dimensions, highlighted above as crucial to preventing new introductions, are the least studied aspect of this socio-ecological phenomenon. Other researchers have suggested that the relatively low level of research effort on introduced species in South America compared with in the rest of the world could reflect a low level of interest by society (Speziale et al. 2012), but Pauchard et al. (2011) demonstrated that invasion biology actually makes up a higher percentage of overall ecological research in Latin America and the Caribbean than internationally. It is possible, though, that increasing public awareness about this phenomenon could help catalyse research and management efforts. On the other hand, our findings here and elsewhere suggest that invasion biology as a discipline is well established in the region, but there need to be appropriate incentives within the scientific system itself to facilitate researchers addressing biological invasions more holistically (Anderson & Valenzuela 2014).

Research is biased not just towards ecological studies, but also towards particular levels of biological organisation and specific approaches. Elsewhere, genetic techniques (e.g. molecular detection of cryptic invaders, reconstructing invasion history, population dynamics; Darling 2015) have proven to be crucial in understanding scenarios of IIMs pre- and post-introduction, during the invasion stage, and subsequently for their management and re-invasion monitoring (Veale et al. 2013, Nathan et al. 2015). Our results showed, however, that these methods are not currently being deployed in southern South America. Likewise, the overall lack of ecosystem studies hinders a more ecologically meaningful understanding of the invasion process, since the population-level and community-level approaches are appropriate for quantifying impacts, but genetic and ecosystem levels permit a more holistic understanding of underlying and emergent processes and properties.

The link between research and management

The increase in research on IIMs in southern South America during the last 10 years coincides with trends in the study of biological invasions throughout Latin America and the Caribbean (Quiroz et al. 2009, Pauchard et al. 2011, Speziale et al. 2012). Researchers have paid a great deal of attention to a few species, such as the North American beaver and the red deer. This could be a problem, since some species are not well studied, but having other species with a critical mass of information, as is the case for North American beavers, demonstrates how basic studies can help drive a political process that has given rise to a binational agreement between Argentina and Chile to eradicate this invasive introduced ecosystem engineer and to restore degraded ecosystems. This demonstrates that research and management can be linked (Anderson et al. 2011, Malmierca et al. 2011).

Overall, this review shows that conceptual and applied integration is still tenuous. Firstly, we found knowledge gaps in both the theory and the practice of invasion biology needed to understand and manage IIMs in southern South America. While more than half of the studies were focused on impacts and autecology, only a few authors addressed underlying ecological patterns and processes, which would allow more general and predictive understanding. Secondly, there is a scarcity of applied studies for management and of research linked with social and political dimensions, which are necessary to integrate this information to the institutional and administrative processes. Thirdly, most management-oriented publications were reviews, which are an important way to summarise existing information, but do not generate new knowledge or enhance techniques with the aim of improving management strategies.

Clearly, social considerations, such as public interest and awareness, but also the social context of science itself, are crucial for implementing effective research and management programmes for IIMs (see also Yan et al. 2001). For example, at Yendegaia National Park (Tierra del Fuego Island, Chile), a violent public backlash occurred when invasive feral horses were killed, leading to the creation of a group called 'Let's Save the Horses of Tierra del Fuego'. This group operates under the belief that they are protecting a 'new' breed called 'Darwin's horses' (https://www.facebook.com/caballos.epeison.australes?fref=). The conflict stopped the control actions and clearly illustrates the importance of public engagement in management and control actions applied to invasive species. Several authors have noted that public opposition can lead to the failure of control or eradication campaigns (Moore et al. 2003, Genovesi 2005), but our findings help to demonstrate that by continuing to conceive of and study biological invasions with a greater focus on their biological drivers and solutions, we continue to miss the complex mosaic of factors that involve individual and social human behaviours at multiple scales (Ricciardi et al. 2011). Therefore, promoting incentives, for example education programmes and public participation related to the management of introduced and invasive species, should be a tool to be deployed in conjunction with traditional activities inherent in environmental control and monitoring. Scientists and managers must also change their research agendas so that they can understand and manage these topics more effectively (Estévez et al. 2015).

Since the overwhelming majority of the studies we reviewed (~80%) were focused on the invasion stage (i.e. when the species begins to spread and cause impacts), researchers are arguably not dedicating the required effort to developing methods for biosecurity or rapid responses. Thus, it is important to enhance early detection and initial rapid responses to introduced species before they become invasive (Lodge et al. 2006, Brunel et al. 2013, Caffrey et al. 2014). Early detection and rapid responses, which are most appropriate when the introduced species are at low densities either in the first stage of the invasion or if a subsequent management action decreases their abundance, are also cost-effective strategies that aim to minimise future expenditures and complement control and eradication efforts (Mehta et al. 2007, Dejean et al. 2012). Together, this suite of approaches has the ultimate goal of resisting biological invasions or restoring the invaded habitat to a natural, seminatural, or otherwise desirable state, as well as providing improved conditions for native species (Westbrooks & Eplee 2011).

Nonetheless, we argue that this is a propitious and opportune time in southern South America to bridge the gaps we and others have identified between the realms of research and management. For example, both Argentina and Chile are developing national strategies to overhaul their approach to invasive species. With the support of two Global Environment Facility grants (see http://www.ambiente.gov.ar/?idseccion=315, http://www.proyectogefeei.cl/), these two countries are undertaking efforts to improve their co-ordination, to reduce the impacts of biological invasions via the elaboration of institutional and regulatory frameworks, and to test pilot projects in specific areas (e.g. Juan Fernandez Islands, Chile) and species (e.g. North American beaver, Argentina and Chile). However, while there has been some interaction and collaboration at the technical level between researchers and managers of both countries, the strategies were planned and presented separately for funding, and subsequently their development has happened without sufficient formal binational or regional coordination, further demonstrating the need to prioritise a better understanding of the political dimensions of both biological invasions and their relationships to society.

RECOMMENDATIONS AND CONCLUSIONS

Specifically, we suggest that the following lessons can be drawn from this review in the context of reformulating national policies and strategies regarding the science and practice of dealing with IIMs in southern South America:

1. Scientists and environmental managers should recognise that there are more IIM species than reported in previous global studies (e.g. by Sax 2001) and that they are present and spread throughout the region, even in ostensibly 'pristine' areas such as the Magellanic subpolar forests of southern Patagonia and numerous national and provincial protected areas (Mittermeier et al. 2003, Rozzi et al. 2012).
2. While many of today's IIMs were introduced at the time of European colonisation, even in the last few decades mammals were still being brought to southern South America or moved internally to new places, demonstrating that policies of biosecurity that limit new releases, escapes, and translocations are urgently needed, not only nationally (e.g. Sanguinetti et al. 2014), but also regionally.
3. The management of biological invasions should incorporate more fully their social and cultural dimensions. To date, ecological impacts have been highlighted in research, while economic and social dimensions and general public perceptions are not evaluated or formally included in either research or management. Recognising the benefits of introductions will also be crucial to establishing socially acceptable and feasible criteria for the management of introduced species. As a result, greater attention should be paid to the human dimensions of biological invasions in both research and practice.
4. There is a long history of introductions for various commercial and cultural reasons, but it is striking that the most common reason for the introduction of mammals that became invasive was hunting. Therefore, serious consideration must be given to designing stricter policies regarding the establishment of introduced species in hunting reserves, and there should be more forceful compliance with existing standards.
5. Monitoring existing populations of IIM will be key for managing these invasions, particularly given that these species may display behaviours or patterns not in line with expectations from their native ranges (e.g. wild boar colonising new biomes in southern South America).
6. Given the major gap in applied research oriented towards practical and management questions that we detected here, it would be advantageous for new national policies to undertake to solve this problem explicitly, by creating 'communities of knowledge', where managers and scientists can work together on the co-production of information. These efforts in turn would benefit from prioritising empirical and experimental research on more applied issues, such as early detection techniques, rapid response actions, and management strategies.
7. Regarding appropriate sites and target species for pilot projects, this review's findings point towards two specific approaches: 1) the Magellanic subpolar forest, the Valdivian temperate forest, and the Patagonian steppe are the most invaded biomes and therefore may be the areas in most need of management strategies; or 2) managers may decide that it is more productive to prioritise areas where there are currently few invasive species (e.g. Humid Chaco or the Sechura and Atacama deserts) to gain experience and credibility in simpler scenarios.
8. The social context of management must be taken into consideration and not just the mere number of IIMs. Therefore, management strategies should include outreach and social involvement programmes to ensure general public acceptance of the management itself. One option is the implementation of citizen science campaigns, not only to achieve social support for the management actions, but also to encourage people to play a leading role in the strategy (Ford-Thompson et al. 2012, Funk et al. 2014). For example, the inhabitants of El Chaltén (a town in Glaciers National Park, Argentina) were crucial to the early detection of invasive American mink, since this area constituted a new invasion front (Fasola & Valenzuela 2014). This citizen science campaign successfully allowed national park managers to find the sites with mink presence quickly and to take action accordingly (Valenzuela et al. 2015).
9. Since economic, logistic, and human resources are limited, we propose the development of a prioritisation tool for IIM management. For example, Valenzuela et al. (2014) found that, based on ecological data, the invasive species that affect ecosystems by several different mechanisms (e.g. North American beaver, wild boar, muskrat, European rabbit) were the highest priority for management in Tierra del Fuego. Terrestrial predators (i.e. American mink, feral dog *Canis lupus familiaris*, South American grey fox, cat *Felis silvestris catus*) were also important to control, as they have strong effects on native communities by modifying food webs via both predation and competition. We argue that the same standards and considerations could be applied to species prioritisations on the mainland, but context-specific considerations should also be incorporated in decision-making, such as feasibility, opportunity costs, and native species of special concern.

In conclusion, the challenge globally, not just for this region, will be to develop an integrated socio-ecological strategy to address biological invasions, where studies and management actions are executed jointly by different organisations and governments at different levels (international, national, regional, provincial, etc.), to achieve holistic management of IIM populations without impediment by political borders.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's web-site.

Appendix S1. Peer-reviewed publications data base.
Appendix S2. Characterisation of invasive introduced mammals.