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Geographic distribution of the European hare (*Lepus europaeus*) in Brazil and new records of occurrence for the Cerrado and Atlantic Forest biomes

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Abstract: The introduction of alien species is among the main causes of biodiversity loss. There are many documented cases of introduced mammals having severe impacts on the ecosystem. The European hare (*Lepus europaeus*), native to Europe and Asia, was introduced to southern Brazil in the 1950s and has since expanded its geographic distribution considerably. In this study, we present a review of the known distribution of the European hare in Brazil, add new records of occurrence that expand the species distribution into southeastern Brazil and estimate the species dispersal rate in Brazil. We compiled a total of 135 distinct localities of occurrence for the species in Brazil, including published records and the previously

unknown localities presented here. These records indicate a dispersal rate of 45.35 km/year for the introduced species. Of these known localities, 15 are in protected areas. Because of its high potential for even greater geographic dispersal and potential impacts on native species through competition and disease transmission, we recommend further research to better assess the species status and the implementation of public policies and management controls, especially in protected areas.

Keywords: alien species; biological invasion; exotic fauna.

Introduction

The introduction of alien species is a major cause of biodiversity loss when the established populations became invasive (Schüttler et al. 2008). Invasive alien species (IAS) range from microorganisms to vertebrates (e.g. avian malaria *Plasmodium relictum* Grassi and Feletti, 1891; Nile perch *Nates niloticus* Linnaeus, 1758 and strawberry guava *Psidium cattleianum* Sabine, 1821). After introduction, the IAS increase in abundance and distribution, being able to cause severe impacts on native species. IAS impacts can result from predation, competition and changes in habitat structure, being able to affect native populations and impact important ecosystem services (Singer et al. 1981, Novillo and Ojeda 2008, Schüttler et al. 2008, Estes et al. 2011).

Mammals were the first organisms to be intentionally introduced around the world for reasons including hunting game, commercialization, domestication for livestock or pet and to control the adverse effects of other invasive species (Long 2003, Clout and Russell 2008). Invasive species of mammals have great ecological plasticity, which allows a successful dispersal to areas outside

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the natural species range (Long 2003, Clout and Russell 2008). In South America there are several examples of introduced mammals (e.g. blackbucks *Antilope cervicapra* Linnaeus, 1758; wild boar *Sus scrofa* Linnaeus, 1758 and the American beaver *Castor canadensis* Kuhl, 1820) that have become invasive and cause negative impacts on the economy, environment and public health (Novillo and Ojeda 2008, Pedrosa et al. 2015).

The ecological threat of IAS is a special concern in protected areas (PA) where the impacts of invasive species can compromise the ecological stability of important areas for biodiversity conservation (Nuñez and Quintero 2002, Sampaio and Schimidt 2013, Ziller and Dechoum 2013). In Brazil, 148 IAS have been documented and 227 records of various IAS were inside PA (Ziller and Dechoum 2013) as a reflection of expansion and intentional introduction in surrounding of PA (Sampaio and Schimidt 2013, Ziller and Dechoum 2013).

The Order Lagomorpha includes some of the most successful invasive species in the world, particularly the European hare *Lepus europaeus* (Pallas, 1778) (Long 2003, Clout and Russell 2008). The European hare is native to grasslands in Europe (except Britain, Ireland and Sweden) and parts of Asia (Iran, Iraq and Israel) (Chapman and Flux 1990, Edwards et al. 2000). The species current distribution includes North America, Central America, South America and Oceania, as a direct consequence of human mediated introductions, characterizing it as an IAS on all of these continents (Long 2003, Smith and Johnston 2008).

The European hare is a terrestrial and nocturnal species (Chapman and Flux 1990), which feeds on grasses and woody plants (Soriguer and Palacios 1994, Puig et al. 2007). In Europe, the European hare serves as a key prey mainly for mesopredators (e.g. red fox *Vulpes vulpes* Linnaeus, 1758; American mink *Mustela vison* Schreber, 1777; Eurasian lynx *Lynx lynx* Linnaeus, 1758; Goshawks *Accipiter* spp. Brisson 1760 and the Eurasian eagle-owl *Bubo bubo* Forster 1817), while in South America, there are records of European hares being preyed on by large (e.g. cougar *Puma concolor* Linnaeus, 1771) and small felids (e.g. Geoffroy's cat *Leopardus geoffroyi* d'Orbigny and Gervais 1844), foxes (*Lycalopex* spp.) and owls (*Bubo* spp.) (Lindström et al. 1986, Yáñez et al. 1986, Novaro et al. 2000, Cossíos 2004, Nabte et al. 2006, Galende and Raffaele 2008, Peters et al. 2009 and Skewes et al. 2012).

European hares first arrived in South America in 1880 from Germany, when they were introduced in Argentina and Chile for hunting game, and were eventually declared an agricultural pest (Grigera and Rapoport 1983). Currently, the species is known to occur in Argentina, Brazil,

Bolivia, Chile, Paraguay, Peru and Uruguay (Auricchio and Olmos 1999, Bonino et al. 2010).

The European hare spread into southern Brazil in the 1950s by means of natural dispersal across the border with Uruguay and through intentional introductions, with the first record made in 1965 and followed by the first population explosion observed in the 1970s and 1980s (Grigera and Rapoport 1983, Long 2003, Costa and Fernandes 2010). The species's invasive condition resulted in an open season for hunting it in the south of Brazil after records of 1965, even though hunting activities were not regulated in any way or for any species at the national level at the time (Auricchio and Olmos 1999).

However, without control programs, including the hunting seasons it in the south of Brazil, which is not allowed anymore, the range of the European hare in Brazil continues to expand (Costa and Fernandes 2010). Determining the species current distribution and rate of dispersal is a starting point for developing and implementing management efforts to control the population growth. The aim of this study is to map the current distribution of the European hare in Brazil, assess the expansion of its distribution and discuss the risks it poses to native flora and fauna in PAs where invasions have already occurred.

Materials and methods

We conducted an extensive literature review in order to compile formal records for the occurrence of European hares in Brazil. We also consulted the database of the *Instituto Hórus de Desenvolvimento e Conservação Ambiental*, which is part of the IBN National Database on Invasive Alien Species (Instituto Hórus 2014), and checked the official records for the occurrence of IAS in PA that is maintained by the *Instituto Chico Mendes de Conservação da Biodiversidade* (ICMBIO 2014). Additionally, we added new records of occurrence for European hares in the Atlantic Forest and Cerrado biomes in two regions of the state of Minas Gerais, southeastern Brazil. We obtained these new records indirectly, through the use of camera traps and opportunistic field observations. The new records were georeferenced and added to the available data compiled from the literature and mapped.

We calculated the dispersal rate of the European hare in Brazil according to the method of Bonino et al. (2010). For this calculation, we considered the first and most southerly record, the most northerly record and various intermediate points of occurrence. Considering the intermediate points was necessary due to the large differences

in landscape physiognomy (e.g. physical obstacles as rivers and mountains) over the trajectory between the first record and the end point. We evaluated the difference in the distance between each point, accounting for the time difference, and thereby obtaining an estimate of the species's dispersal rate in km/year for each trajectory to the extremes of its current known distribution. With all of these intermediate speeds we calculated the species's mean rate of dispersal.

Results

We identified 131 different localities for the European hare in Brazil (Table 1), 67 of the records are from the literature and 64 are from the *Instituto Hórus* and ICMBIO databases. The percentages of these localities are distributed regionally as follows: south (45.03%), southeast (53.43%) and midwest (1.52%) (Figure 1). The species's presence is greater in areas where native vegetation has suffered from

Table 1: Known localities of occurrence for *Lepus europaeus* in Brazil.

Location	State	Source
Planura, Frutal e Capinópolis	MG	Bonino et al. 2010
Pouso Alegre	MG	Costa and Fernandes 2010
Curitiba, Medianeira, Paranavaí, Piraquara e Ponta Grossa	PR	Bonino et al. 2010
São Mateus do Sul, Rio Jordão, Foz do Jordão, Castro, Estância Ypiranga, Sta Vitória do Palmar	PR	Auricchio and Olmos 1999
Guarapuava, Pinhão, Farol, Campo Mourão, Fenix, Londrina, Ibiporã, Jataizinho, Cornélio Procópio	PR	Auricchio and Olmos 1999
São Jorge do Patrocínio, São José dos Pinhais, Toledo, Cascavel	PR	Instituto Hórus 2014
Campus da Universidade Federal de Santa Maria (UFSM)	RS	Santos et al. 2008
Santa Vitória do Palmar	RS	Auricchio and Olmos 1999
Santana do Livramento	RS	Peters et al. 2009
Bom Jesus, Arroio Grande, Alegrete	RS	Kasper et al. 2012
São Francisco de Paula/Distrito de Rincão dos Kroeff/Distrito de Potreiro Velho	RS	Marques et al. 2011
Rio Grande	RS	Oliveira et al. 2013
Barra do Guaraí	RS	Bianchin et al. 2011
Cambará do Sul, Quaraí, Rosário do Sul, Maçambará, Viamão, Itaqui, Muitos Capões, Uruguaiana, Palmares do Sul, Tramandaí, Derrubadas, Jaquirana	RS	Instituto Hórus 2014
Chapecó	SC	Cherem 2005
Campo Belo do Sul	SC	Kasper et al. 2012
Timbé do Sul, Campos Novos, Siderópolis, Subestação de Barra Grande	SC	Cherem 2005
Vitor Meireles, Doutor Pedrinho, Aurora, São Domingos, Ipuacu, Três Barras	SC	Instituto Hórus 2014
Ponte Serrada e Passos Maia; Praia Grande; Jacinto Machado	SC	ICMBIO 2014
Subestação de Machadinho	SC/RS	Cherem 2005
Jundiá	SP	Carvalho et al. 2013
Piracicaba	SP	Gheler-Costa et al. 2002
Icém, Nantes, Pirapozinho, Presidente Epitácio, Rancharia, Sandovalina, Teodoro Sampaio	SP	Bonino et al. 2010
Itirapina Ipeúna	SP	Hülle 2006, Dotta and Verdade 2007
Bernadino de Campos, São Manoel, Itararé, Piedade, Ibiúna, Campos Novos Paulista, Ocaucu, Bauru, Pirajui, Tupã, Parapuã, Rio Feio, Luiziziânia, Jatobá, Alto Alegre, Assis	SP	Auricchio and Olmos 1999
Botucatu	SP	Antunes et al. 2010
São Carlos	SP	Dias et al. 2012
Cotia, Caiuá, Presidente Venceslau, Ribeirão Grande, Guapiara, Sete Barras, Iporanga, Eldorado, Franco da Rocha, Mirante do Paranapanema, Luís Antônio, Álvares Machado, Anhumas, Estrela do Norte, Euclides da Cunha Paulista, Iepê, Indiana, Marabá Paulista, Martinópolis, São Miguel Arcanjo, Capão Bonito, Tapiraí, Narandiba, Piquerobi, Presidente Bernardes, Presidente Prudente, Regente Feijó, Rosana, Santa Rita do Passa Quatro, Santo Anastácio, Taciba, Tarabai, Alvinlândia, Gália, Lupércio, Garça, Pirassununga, Iporanga	SP	Instituto Hórus 2014
Porto Rico (Taquarussu e Baitaporã)	MS	Aguiar et al. 2007
Itumbiara	GO	Instituto Hórus 2014



Figure 1: New records for European hare (*Lepus europaeus*) in Brazil. (A) August 2012, Parque Nacional da Serra da Canastra, MG (B) November 2013, RPPN Santuário do Caraça, MG (C) June 2012, Araxá, MG (D) August 2013, RPPN Alto Montana, Itamonte, MG.

human impacts (deforestation, fragmentation, fires) that have caused drastic changes in the landscape in the Atlantic Forest (70.50%), Cerrado (15.82%) and grassland areas of the Pampas (10.79%). Of the localities reported in the literature, 12 were in PA, IUCN categories Ia, II, IV and V (Table 2).

The first record of European hare in Brazil, published in literature, was in *Santa Vitória do Palmar*, RS, southern region, in 1982 (Table 1). It took 10 years for the species to be registered in the southeast region, in *Itararé*, SP, and more 11 years for the first record in the midwest in Porto Rico (*Taquarussu e Baitaporã*, MS). After 33 years the northern border of the species' occurrence is *Itumbiara*, GO, midwest (Table 1). The time spent to migrate from the Atlantic Forest biome to Cerrado was around 21 years. New records both in southeast (*Itaperina, Itapeuna, São Carlos* – SP; *Pouso Alegre* – MG) and in the south (*Arroio Grande, Alegrete* – RS; *Chapecó, Timbé do Sul* – SC) suggest that expansion of the species within already invaded areas is currently underway.

In addition to the localities described above, we added ten unpublished records, nine of them in PA, in four regions of Cerrado and Atlantic Forest. In the Atlantic Forest, three records are from *Serra da Mantiqueira*, acquired using photographic trapping methods in August 2013 (n=2) and March 2014 (n=1). These records were made in semi-deciduous seasonal forest habitat at the *Alto Montana* Private Natural Heritage Reserve (*Reserva Particular do Patrimônio Natural – RPPN*) in the Itamonte, MG (44°48'4.02"W, 22°2'8.12"S) (Figure 2). Records from August were made on the same day, sequentially and over a short period of time on the same trail and were probably of the same specimen.

In the ecotonal region between the Atlantic Forest and Cerrado biomes, we made one record in November 2013 at the *Santuário do Caraça* RPPN (43°29'18.31"W, 20°5'53.92"S), located in the *Serra do Espinhaço* in Catas Altas, MG. This record was made using camera traps in a regeneration and management area of the RPPN at an altitude of 758 m. This represents the first record of an IAS

Table 2: Protected Areas (PA), in Brazil with known records of occurrence for *Lepus europaeus*.

IUCN level	Name of UC	Location	Biome
Sensu Strict Protected Area	Reserva Biológica Estadual do Aguai	Morro Grande, Nova Veneza, Siderópolis e Treviso, SC	Atlantic Forest
	Reserva Biológica da Serra do Japi	Jundiá, SP	Atlantic Forest
	Estação Ecológica de Aracuri-Esmeralda	Muitos Capões, SP	Atlantic Forest
	Estação Ecológica Mico Mico-leão-preto	Teodoro Sampaio, Euclides da Cunha Paulista, Presidente Epitácio, Marabá Paulista, SP	Atlantic Forest
Habitat/Species Management Area	Reserva Particular do Patrimônio Natural Alto Montana	Itamonte, MG	Atlantic Forest
	Reserva Particular do Patrimônio Natural Santuário do Caraça	Catas Altas e Santa Bárbara	Atlantic Forest/Cerrado
National Park	Parque Municipal de Pouso Alegre	Pouso Alegre, MG	Atlantic Forest
	Parque Estadual de Caxambu	Castro, PR	Atlantic Forest
	Parque Estadual do Espinilho	Barra do Guaraí, RS	Pampa
	Parque Estadual Intervales	Ribeirão Grande, Guapiara, Iporanga, Eldorado e Sete Barras, SP	Atlantic Forest
	Parque Nacional Serra da Canastra	Capitólio, Vargem Bonita, São João Batista do Glória e Delfinópolis, MG	Cerrado
Protected Landscape/Seascape	Parque Nacional das Araucárias	Ponte Serrada e Passos Maia, SC	Atlantic Forest
	Parque Nacional Aparados da Serra e Serra Geral	Cambará do Sul, Jacinto Machado e Praia Grande	Atlantic Forest
Protected area with sustainable use of natural resources	Área de Preservação Ambiental Ibirapuitã	Alegrete, Quaraí, Santana do Livramento, Rosário do Sul RS	Pampa
	Floresta Nacional de São Francisco de Paula	São Francisco de Paula, RS	Pampa

for the area. In contrast to the abundant records of *Sylvilagus brasiliensis* Linnaeus 1758 in the reserve, accounting for 125 of the 547 valid camera trap records (individual/species \times day).

In the Cerrado biome, we documented five records for the European hare in *Serra da Canastra* National Park (PNSC). The first two occurrences were recorded using camera traps (Figure 2) on 1 July 2012 at 15:53 and 6 August 2012 at 00:17 in grassland habitat (46°34'11.76"W, 20°14'50.20"S and 46°28'39.73"W, 20°12'45.37"S, respectively).

The other three occurrence records were made by direct observation in the field when animals were seen crossing different segments of roadways in PNSC, all after dusk. The first observation was made on the 13 July 2013 at 17:43 (46°35'16.88"W, 20°11'40.30"S) in an area surrounded by typical Cerrado vegetation types, including *campo sujo* and *campo limpo* phytophysiology. The second record was made on the 9th of October at 18:33 (46°33'6.89"W, 20°15'37.38"S) in area of predominantly *campo limpo* habitat with *campos rupestres* influence. The third observation was made on the 18th of October at 19:05 (46°34'11.15"W, 20°12'46.58"S) in a *campo limpo* area surrounded by *campo sujo*, *campo úmido*, and small woodland fragments. Also in the Cerrado biome, at a distance of

about 60 km from PNSC, in the municipality of Araxá, an individual of European hare (approximately 58.5cm long) was road-killed by a vehicle along the MG-146 highway (19°42'51.45"S, 46°55'43.59"W). This particular record was made on the 12 June 2012 at about 23:30, in an area dominated by regions of *campo limpo* between agricultural areas, pastures and semi-deciduous seasonal forest fragments in different stages of succession (Figure 2).

To calculate the species rate of dispersal, the municipality of *Santa Vitória do Palmar* in the state of *Rio Grande do Sul*, was considered as the first record in southern Brazil, with the most northerly record coming from the city of *Itumbiara*, located in the state of *Goiás*. Between these points, we considered records of occurrence from eleven other cities (*Arroio Grande*, *Rio Grande*, *Santa Maria*, *Bom Jesus* – RS; *Campo Belo do Sul*, *Campos Novos*, *Chapecó* – SC; *Londrina* – PR; *Rio Feio*, *Icém* – SP; *Capinópolis* – MG) in calculating the rate of dispersal, estimated to be 45.35 km/year.

Discussion

The European hare has succeeded in colonizing and expanding its distribution in Brazil. The species is predominantly

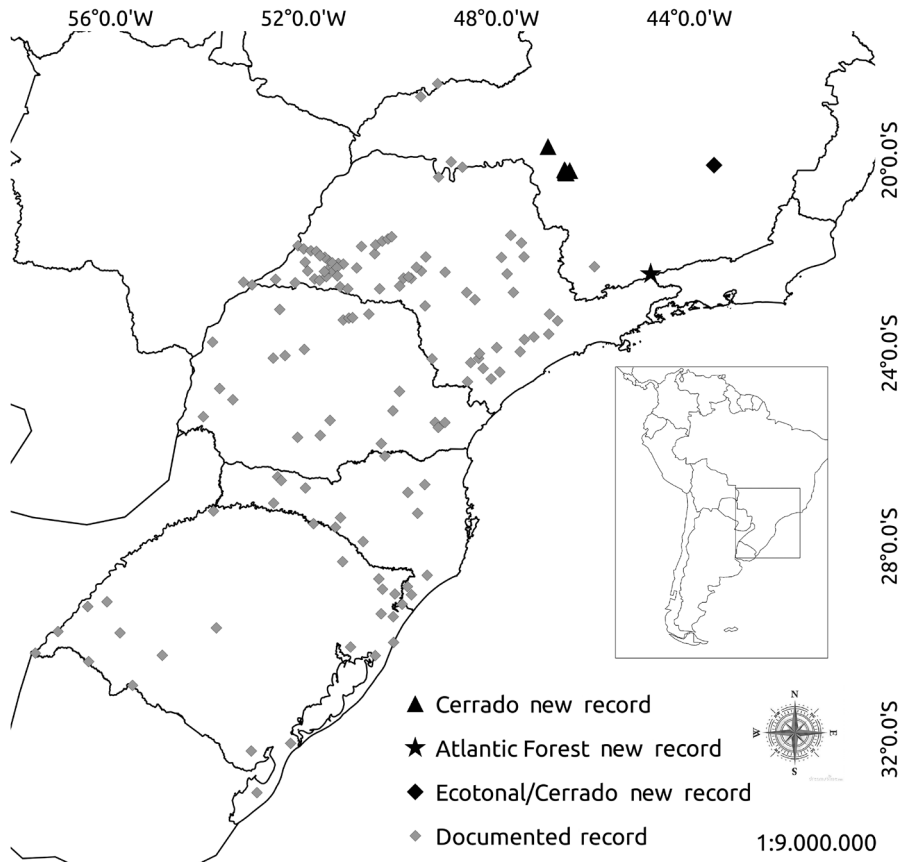


Figure 2: Current known geographic distribution of the European hare (*Lepus europaeus*) in Brazil.

distributed in grassland vegetation in the South and the Southern Atlantic Rain Forest, but reach the Cerrado and the Atlantic Rain Forest-Cerrado ecotone in the Southeast region of the country, the current Northern border for the species. Records of the species occurrence in the Cerrado are sporadic (this article, Bonino et al. 2010, Costa and Fernandes 2010). However, the Cerrado biome holds great potential for the species to increase its distribution northward in Brazil, as has happened in other South American countries (Novillo and Ojeda 2008, Bonino et al. 2010).

We estimated a dispersal rate for European hares in Brazil 50% higher than that suggested by Bonino et al. (2010), and also greater than estimates by the same author for this species in other countries in South America. The considerable increase in the estimated rate of dispersal over such a short period of time, around five years, confirms the species capacity of fast geographic expansion. The success of European hare invasion is related to a high degree of ecological plasticity and the fact that the species is less susceptible to diseases that affect the native lagomorphs (Thulin 2003, Bonino et al. 2010, Reid 2011). *Lepus europaeus* dispersal ability may also be supported by a high degree of occupation success in both conserved and

altered landscapes, ranging from pastures, *Pinus* spp. and *Eucalyptus* spp. plantations (Auricchio and Olmos 1999) to well conserved PAs, as demonstrated by our new records. The practice of hunting of potential predators in Southern Brazil, such as wild canids and felids (De La Sancha et al. 2009), and changes of land use from forested areas to crop monocultures, a highly-attractive food resource for European hares, may have a combined effect that has facilitated the species invasion (De La Sancha et al. 2009, Bonino et al. 2010).

The presence of IAS spans a wide range of PAs in Brazil, including Sensu Strict Protected Area, National Parks, Protected areas with sustainable use of natural resources, Habitat/Species Management Areas and Protected Landscape/Seascape (Rylands and Brandon 2005, Sampaio and Schmidt 2013, Ziller and Dechoum 2013, IUCN 2014). Of the four new records for European hare documented here, three were made within Habitat/Species Management Area (RPPN Alto Montana e RPPN Santuário do Caraça) and National Park (PNSC) (Table 2) (Rylands and Brandon 2005, IUCN 2014). These records suggest that *L. europaeus* is able to invade undisturbed ecosystems, very different than the heavily disturbed

and fragmented open areas typical of previous European hare occurrence records in other regions of Brazil (Gheler-Costa et al. 2002, Cherem 2005, Bianchin et al. 2011) and the world (Chapman and Flux 1990, Edwards et al. 2000). Records of hares in such areas are a growing concern. The PAs where hares were recorded harbors many endemic and locally adapted plant populations that are vulnerable to high predation intensity. The increase in hare density in PAs may have a strong impact in threatened endemic plant species vulnerable to local extinctions (Fernandes et al. 2014, Leles et al. 2015).

The expansion of the European hare can have a range of negative impacts on native species. All new records reported here were made in biodiversity hotspots biomes (Myers et al. 2000) including one of the ten most irreplaceable areas in the world for biodiversity conservation (*Serra da Mantiqueira – Alto Montana* RPPN) (Le Saout et al. 2013); a key conservation reserve for Atlantic Forest by UNESCO (*Santuário Caraça* RPPN) (Santuário do Caraça 2014); and in *Serra da Canastra* that is highlighted among the 18 defined “Special Relevance Area” (*Serra da Canastra* – PNSC) and “Area of Extremely High Biological Importance” (Drummond et al. 2005, MMA 2005). PNSC records show an occupation area by European hares in 2012/2013 of 48 km², which represents almost 7% of the total protected area in the reserve.

There is a lack of information regarding the effect of European hares invasion in the native fauna of Brazil, however, studies in Argentina and Europe have shown niche overlap, and possible competition with native species (Stott 2003, Thulin 2003, Galende and Raffaele 2008, Reid 2011). In Europe, the environmental pressures exerted by European hare invasions (in places where is not native eg. Britain, Ireland and Sweden) was shown to be able to cause more ecological impacts than hunting, predation or disease (Thulin 2003). Furthermore, the European hare can also act as vectors for diseases such as European Brown Hare Syndrome and parasites, such as *Fasciola hepatica*, Pseudotuberculozes, and Coccidiosis, that can put native species at risk (Grigera and Rapoport 1983, Auricchio and Olmos 1999, Edwards et al. 2000, Kleiman et al. 2004, Novillo and Ojeda 2008).

Despite the negative points, some authors have reported that invasion of European hare may have certain positive effects, such as reducing predation pressure on native species and domestic animals (Jaksic 1998), potentially benefiting native carnivores (Jaksic 1998, Novillo and Ojeda 2008). However, in South America there is a lack of information regarding the impacts of European hare to draw a clear picture of its environmental consequences (Bonino et al. 2010). Due to its successful invasion

(Novillo and Ojeda 2008), studies assessing the impact of European hares on native fauna are urgent.

The limitations of laws regarding wildlife management under the current complexity IAS have lagged the development of conservation strategies in Brazil. The proper diagnoses of the invasion process and its ecological threats for the environment is lacking for most IAS in Brazil (Sampaio and Schmidt 2013). Control techniques of alien species must be strategically evaluated in management plans of PA, as these serve as the main ways of reducing the impacts that cause biodiversity loss and environmental degradation (Vallejo 2002). These strategies will be effective if the control techniques and management extended to the surrounding area and be strategically evaluated with the local community. Some notable advances have been made in Brazil, such as recent regulations to control the spread of wild boars (*Sus scrofa*), an IAS that is now common in many PAs (Hegel and Marini 2013, Trovati and Munerato 2013, Pedrosa et al. 2015). The creation of the Law 9605/1998 was first step to ban introduction of alien species, but better tools to improve the control of invasive species are lacking. Following the strategy of official lists of endangered species, we suggest the creation of regional lists of alien species with the possibility for live update of species records and associated ecological information. Regional IAS lists are available for few regions of Brazil, such as in the states of *Rio Grande do Sul* (Portaria SEMA n° 79, 31 October 2013), *Paraná* (Portaria IAP N° 125 of 07 August 2009) and *Santa Catarina* (Resolução CONSEMA N° 11 of 17 December de 2010). Likewise, a national research program focused in understanding the ecological dynamics of European hares in the invaded areas, specially PAs, would have a great positive impact. Understanding these factors can clarify the species selection strategies and habitat use in the different environments it is colonizing, helping the creation of more effective conservation planning in Brazil.

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