ESCUELA DE PREGRADO – FACULTAD DE CIENCIAS – UNIVERSIDAD DE CHILE

"MAMÍFEROS INVASORES EN CHILE: EVALUACIÓN DE ASPECTOS BIOLÓGICOS PARA SU ERRADICACIÓN"

Seminario de Título entregado a la Universidad de Chile en cumplimiento parcial de los requisitos para optar al Título de Bióloga con mención en Medio Ambiente.

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ESCUELA DE PREGRADO – FACULTAD DE CIENCIAS – UNIVERSIDAD DE CHILE

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Se informa a la Escuela de Pregrado de la Facultad de Ciencias, de la Universidad de Chile que el Seminario de Título, presentado por la Srta. Romina Fernanda Acevedo Torres.

"MAMÍFEROS INVASORES EN CHILE: EVALUACIÓN DE ASPECTOS BIOLÓGICOS PARA SU ERRADICACIÓN"

Ha sido aprobado por la Comisión de Evaluación, en cumplimiento parcial de los requisitos para optar al Título de Bióloga con mención en Medio Ambiente.

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Santiago de Chile, Octubre 2013

La civilización que confunde a los relojes con el tiempo, al crecimiento con el desarrollo y a lo grandote con la grandeza, también confunde a la naturaleza con el paisaje, mientras el mundo, laberinto sin centro, se dedica a romper su propio cielo.

Eduardo Galeano

AGRADECIMIENTOS

Al profesor Javier Simonetti por su dedicación y orientación como tutor de mi Seminario de Título, y por sus continuas enseñanzas.

A mi familia por su amor y compañía durante este proceso.

A Amaro por ser mi gran compañero.

Y a todas aquellas personas que con su existencia han hecho la mía más feliz.

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SUMMARY

Eradication of invasive species, both during the planning and implementation stages, it is in infancy in Chile. However, there is valuable knowledge in the world on the eradication which we can learn to have a better manage our invasive species. In this sense, the expert consultation about the most important questions of target species biology for eradication goals provides an important opportunity to determine whether in Chile we have this information to eradicate invasive species, particularly mammals. Experts currently involved in practical field eradication and the Chilean Cooperating Committee for the Control of Invasive Species (COCEI) members were consulted about the importance of a list of aspects of target species biology to implement eradication programs. This information was compared with the reported information for the thirteen invasive mammals species present in Chile. Our results indicate that information about species biology is not sufficient to support the requirements of experts to eradication purposes. Several species have been poorly studied even been considered part of the world's most harmful species. Invasive species research should aim to resolve issues regarding their management. We must be aware that they are one of the major threats to biodiversity, and that the eradication of invasive species is one of the most powerful tools to eliminate these threats.

Keywords: invasive mammals, eradication, invasive species management

INTRODUCTION

Invasive alien species are the second main cause of biodiversity loss after habitat destruction and fragmentation (Vitousek *et al.* 1997), being the primary driver of species extinction on islands (Clout & Veitch, 2002; Keitt *et al.* 2011). Effects of invasive species occur at all levels of organization from the genetic to the ecosystem. They can affect biodiversity through predation, parasitism, herbivory, pathogen transmission, habitat modification, hybridization and competition with native species (e.g. Blackburn *et al.* 2004; Croll *et al.* 2005; Fukami *et al.* 2006; Henderson, 2010).

The most effective way to address these threats is the prevention of new unwanted introductions, by establishing strict biosecurity policies at the national, regional and global scale. However, when prevention fails, eradication is one of the most concrete and cost-effective responses to invasive species and this tool can eventually reverse the present rate of biodiversity loss (Carrion *et al.* 2011; Genovesi, 2011). In fact, there is strong evidence that eradication of invasive species has resulted in the recovery of native biodiversity (e.g., Smith, 2006; Aguirre-Muñoz *et al.* 2011; Kessler, 2011; Rauzon *et al.* 2011; Watari *et al.* 2011).

Eradications of invasive species are not a rare event. Around the world more than 1000 successful eradications have been completed of which most have involved invasive vertebrate on islands, especially mammals (Glen *et al.* 2013). The most commonly eradicate have been *Rattus* sp. (> 350) and *Capra hircus* (> 160), followed by *Felis catus* (> 90), *Sus scrofa* (> 55) and *Oryctolagus cuniculus* (> 45). The rate of vertebrate eradication on islands has increased strongly during the last time, being in the last thirty years close to 20 eradications per year (Keitt *et al.* 2011). Along with increased frequency of eradications also came an increase in the size of islands from which invasive vertebrates have been eradicated (Keitt *et al.* 2011). For example, Project Isabela, the world's largest island restoration effort to date, involved the removal of >140.000 goats from >500.000 ha in the Galápagos National Park. However, eradication attempts are not limited to islands. In the last time, eradication opportunities are increasingly being created in mainland sites by the use of pest-exclusion fences to protect areas of high conservation value or to create 'islands' of protected habitat for native fauna (Day & MacGibbon, 2007).

Among countries with more experience in vertebrates eradications on islands are New Zealand with about 300 eradication events, followed by Australia (>150), United States (>130), France (>60) and Mexico (>30) (Keitt *et al.* 2011). The experience gained in these countries has allowed in recent decades a considerable progress in strategies and techniques for achieving eradication goals (e.g. Veitch *et al.* 2011). In fact, in different parts of world have been formed professional groups with an extensive expertise in the design and implementation of eradication programs of vertebrate invaders (e.g., Landcare Research in New Zealand, Galápagos National Park Service and Charles Darwin Foundation in Galápagos Islands, Island Conservation in places like Insular Caribbean, Hawai'i and tropical Pacific, and South America).

There is a widely accepted set of required conditions to successfully eradicate a population (Parkes *et al.* 1990; Bomford & O'Brien, 1995): (1) target species must be removed at rates faster than their rate of increase at all population densities; (2) immigration must be zero; (3) all target animals must be put at risk to the methods being applied; (4) individuals must be detected at low densities; (5) discounted benefit-cost analysis favors eradication over sustained control; and (6) suitable socio-political environment. Conditions 1-4 largely depend on the biological traits of the target species; therefore, managers require knowledge of the biology and ecology of target species in order to determine eradication feasibility (Genovesi, 2007). For example, information about rate of increases allows estimating the rate at which removal should proceed to successfully complete eradication, and understanding immigration (including rate) is critical to manage the reinvasion risk. Measurements of home range size can inform decisions about the optimum spacing of toxic baits or traps when are used these eradication techniques, and so ensuring the access of all individuals to removal methods (Edwards *et al.* 2011). Observations on habitat use are useful to identify zones that are most likely to hold individuals, and to detecting sites that might act as refuge for the species during eradication efforts (Parkes, 2008). Diet studies can highlight the importance of particular food resource to the target species and thus the likely effectiveness of the eradication attempt (Fitzgerald *et al.* 1991). For example, eradications may be most likely to succeed when this main food is scarce (Veitch, 1985). On the other hand, knowledge about species interactions (e.g., competitive and trophic interactions) can help managers to identify and avoid undesirable outcomes of removal, such as declines in native populations and ecological release of other exotic populations. This information can help managers make better decisions regarding the management of invasive species, and take the measures appropriate to prevent or mitigate the undesirable effects when these have been anticipated. The success or failure of an eradication program may be largely determined by the degree of knowledge of target species biology in their new range of introduction (e.g., Gosling & Baker, 1989), so it is important to know which aspects of the species must be evaluated when planning eradication.

In Chile, the study of introduced species dates back at least to the late nineteenth century. Philippi (1885) provided a seminal review of animals introduced since the Spanish conquest. Some domestic animals were introduced intentionally (e.g., goats, pigs, poultry) and others arrived inadvertently (e.g., rats). Currently, in Chile there are 22 species of terrestrial vertebrates listed as introduced invaders (Jaksic, 1998; Iriarte *et al.* 2005). Thirteen of these are mammals (Table 1).

Table 1. Invasive mammals of Chile. Information taken from Jaksic, 1998.

Invader species	Scientific name	Status[a]	When	Where
American beaver	*Castor canadeniss*	Expan.	1956	Tierra del Fuego
American mink	*Mustela vison*	Introd.	1987	Aysén
Black rat	*Rattus rattus*	Introd.	1600s	Central Chile
Coatimundi	*Nasua nasua*	Introd.	1935	Juan Fernández
European hare	*Lepus europaeus*	Expand.	1896	Magallanes
European rabbit	*Oryctolagus cuniculus*	Introd.	1884	Central Chile
Fallow deer	*Dama dama*	Introd.	1950s	Osorno
Feral goat	*Capra hircus*	Introd.	1954	Juan Fernández
House mouse	*Mus musculus*	Introd.	1600s	Central chile
Muskrat	*Ondatra zibethicus*	Expand.	1956	Tierra del Fuego
Norway rat	*Rattus norvegicus*	Introd.	1800s	Central Chile
Red deer	*Cervus elaphus*	Introd.	1950s	Osorno
Wild boar	*Sus scrofa*	Expand.	1960s	Osorno

[a] Introd. = deliberately introduced to Chile; Expan. = naturally expanding its range from Argentina.

Some of these mammals have profoundly altered communities and landscapes both continental and insular Chile. For example, rabbits are mainly responsible for the pattern of herbaceous distribution in the matorral of central Chile (Jaksic & Fuentes, 1980). Grazing activity by rabbits may be halting the secondary succession process, shifting the matorral composition toward less palatable shrub species, and/or broading the spacing between shrub clumps (Fuentes *et al.* 1983). Goats also have effects on the matorral. They reduce shrub cover, favoring the abundance of rabbits to create open patches, and affecting small native mammals that inhabit undisturbed patches (Simonetti, 1983). In Tierra del Fuego Archipelago, one the last places on Earth that may still be considered wild (Silva & Saavedra, 2008), American beavers and muskrats are the most widely distributed species (Valenzuela *et al.* 2012). Beavers have modified the original courses and characteristics of native hydrological systems, by land flooding and sedimentation (Skewes *et al.* 1999). The most evident impacts are observed in riparian vegetation, used for construction of dams and direct consumption. They became forest in early successional gaps, and change the assembly plant to include a greater species richness and abundant herbaceous layer (Anderson *et al.* 2006a). Muskrat is considered harmful by its tunneling activities, it damages earthen dams and irrigation ditches, causing floods and loss of habitat (Jaksic *et al.* 2002). Other invasive mammals present in the Fuegian Archipelago are American minks, rabbits, and wild boars, all with a recognized potential to cause significant ecological impacts (Jaksic, 1998; Silva & Saavedra, 2008). On the other hand, invasive herbivores in Juan Fernández Archipelago such as goats and rabbits are among the most important factors threatening the natural regeneration of native flora. This is critical considering that 62.1% of the native vascular flora is endemic, and that 75% of it is under threat of extinction (Cuevas & Van Leersum, 2001). The coatimundi, which apparently was introduced to control black rat populations in Juan Fernandez (Miller and Rottmann, 1976), would be responsible for declines in native bird populations, including endangered Juan Fernández firecrown (*Sephanoides fernandensis*) (Colwell, 1989). Eradication of invasive mammals is, therefore, necessary to reduce the threats to indigenous species and restore the diversity and functioning of Chilean ecosystems.

Currently, the chief governmental control of invasive terrestrial species resides in the Ministry of Agriculture through the Agriculture and Livestock Service (SAG, in Spanish), and Forest Service (CONAF, in Spanish). Both services have sponsored programs to control and monitor invasive mammal species, but eradication has been only occasionally implemented as a management measure (e.g., Ojeda *et al.* 2003). As an expression of the concern triggered by invasive species, and as a need to respond to the resolutions adopted by the Convention on Biological Diversity (ratified by Chile in 1994), in 2005 was created the Operating Committee for the Control of Invasive Species (COCEI, in Spanish). This organism encompasses all the public institutions involved with the management of alien species, coordinated by the Ministry of Environment (MMA, in Spanish). Its main goal is to design and implement the Integrated National Programme for Management of Invasive Alien Species, targeting to reduce environmental degradation caused by invasive species through prevention, control, or eradication (Fuentes & Pauchard, 2010)

In this context, we analyze whether the necessary biological information to support decision-making in potential programs to eradicate invasive mammals in Chile is available. While there is information on Chilean terrestrial vertebrates including exotic ones (e.g., Jaksic, 1997), we explored if this information is necessary and sufficient to comply with that required to develop and carry out a successful eradication. Furthermore, we want to know if information on the biology of the target species collected in a given region might be transferred to another region where the species is invasive in order to support eradication efforts. Thus, the purposes of this research are to assess a) which aspects of the species biology must be known when planning an eradication program through a consultation to professionals involved in invasive mammal eradications in different parts of the world, b) whether this information is available for thirteen invasive mammals in Chile, and c) whether information about target species biology can be transferred between two regions where the species is present. We hope that research on invasive mammal species in Chile is correlated with the information requirements of the experts in order to advance towards the implementation of eradication programs for these species where possible.

METHODS

Survey

An expert opinion survey was conducted to asses which information on target species biology is required to carry out a successful eradication (Appendix 1). The survey was composed of three parts. The first one evaluated the respondent's assessment regarding the importance of a list of biological aspects for the design of an eradication program of a mammalian species (Table 2). Variables were collected from different publications that include some of these aspects in eradication programs of mammals (e.g., Bomford & O'Brien, 1995; Genovesi, 2007; Roy *et al.* 2009). A four points Likert scale was used (1 = irrelevant, 2 = somewhat, 3 = important and 4 = very important). Respondents were asked to add other aspects they consider important in case these were not included already in the list. The second part assessed the experience of respondents in the eradication of thirteen invasive mammals present in Chile. Finally, the survey included an open question in order to obtain the opinion of respondents about the validity to transfer biological information between two regions where invasive species are present.

The survey was distributed via e-mail to a group of 32 experts currently involved in practical field eradication of mammalian species, and also to members of the Operating Committee for the Control of Invasive Species (COCEI, in Spanish). This committee is comprised by 28 permanent representatives and five additional guests. To evaluate the level of agreement among respondents within each group we carried out a Kendall's coefficient of concordance. Also, we carried out a Spearman's correlation among the most important variables for eradication experts and COCEI members.

Table 2. List of aspects of target species biology consulted to eradication experts and COCEI members for eradication purposes (sources: Bomford & O´Brien 1995; Genovesi, 2007; Roy *et al.* 2009).

	Biological aspect
Population ecology	Abundance
	Age at first reproduction
	Annual rates of increase
	Inmigration rate
	Minimun viable population size
	Population age structure
	Population density
Spatial ecology	Dispersal rate
	Distribution
	Habitat use
	Home range
Trophic ecology	Diet
	Trophic relationships

Literature search

On the other hand, we conducted a literature search of scientific articles in Chile on the thirteen mammals considered invaders (Jaksic, 1998; Iriarte *et al.* 2005). A combination of the Latin name of each species and Chile was used as keywords in ISI Web of Knowledge, EBSCO, and Scielo databases. Additionally, we searched the website of the Centre for Advanced Studies in Ecology and Biodiversity (CASEB). All scientific publications until December 2012 were collected. Grey literature (e.g., technical reports, theses and dissertations) was not included. The topics of the articles were classified for each species according to the categories of biological information listed in Table 2, including aspects suggested by respondents. Each article could address more than one aspect of the list. Finally, we carried out Spearman's correlations among the expert opinion about biological information relevant for eradication goals and the topics covered in the publications.

RESULTS

A total of 20 (64.5%) eradication experts involved in practical field eradication, but only six (18.2%) Operating Committee for the Control of Invasive Species (COCEI) members responded the survey (Appendix 2 and 3). Eradication experts have participated in eradication programs of twelve invasive mammals present in Chile. They have been extensively involved in campaigns to eradicate black rats (*Rattus rattus*), feral cats (*Felis catus*), Norway rat (*Rattus norvegicus*), house mice (*Mus musculus*), feral goats (*Capra hircus*) and European rabbits (*Oryctolagus cuniculus*). Seventy percent of eradication experts also participated in eradicating others mammals, such as brushtail possum (*Trichosurus vulpecula*), European red fox (*Vulpes vulpes*), nutria (*Myoscastor coypus*), Pacific rat (*Rattus exulans*) and stoat (*Mustela erminea*). On the other hand, four of six of COCEI members responding to the survey participated in the eradication of at least one of the thirteen invasive mammals. Two COCEI members have been involved in programs to eradicate American beaver (*Castor canadensis*), one in the eradication of mink (*Mustela vison*), one in the eradication of European rabbits, and one in the eradication of the wild boar (Fig.1).

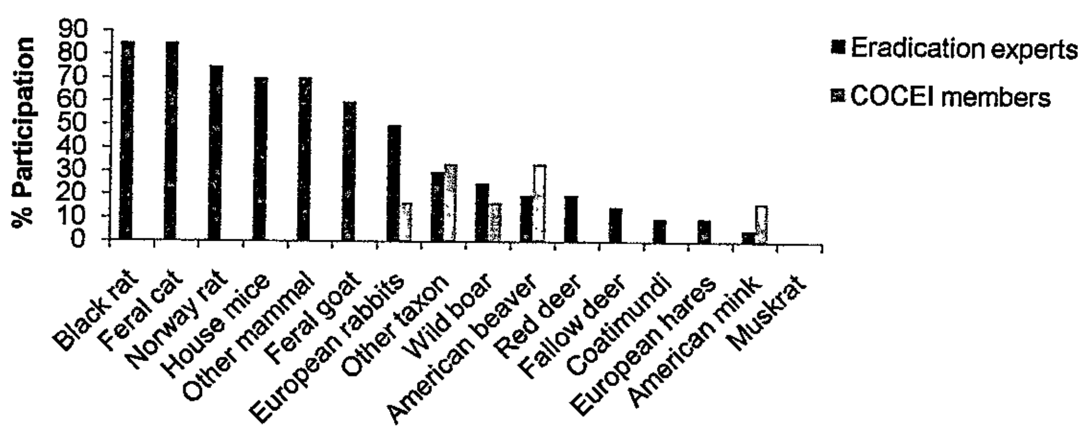

Figure 1. Participation of experts and COCEI members in programs to eradicate invasive mammals.

Importance of biological information

There was a high level of agreement among eradication experts about importance of the different biological information (Kendall's W= 0.62; p <0.001). On the other hand, COCEI members, despite the small sample size, also reached broad agreement (Kendall's W= 0.51; p <0,001). The most important variables (important and very important categories) considered by both groups is positively correlated (r_s= 0.59; p< 0.05). However, COCEI members attributed, in general, similar importance to the different biological aspects, without showing a clear hierarchy of relevance (Fig. 2). This is more apparent when we consider only the thirteen aspects included in the original list.

Meanwhile, eradication experts considered very important or important information on immigration rate, annual rate of increase, home range, habitat use, diet, distribution, population density, and dispersal rate for eradication goals (Fig. 3). They attributed low importance to population age structure and minimum viable population size. New topics added by experts include information on behavior (e.g., social behavior, change in behavior with low density, behavior towards eradication methods), other reproduction aspects (e.g., breeding season, length of pregnancy, litter size) and impacts. On the other hand, COCEI members added to the above historical aspects of invasion, parasites and diseases, and predators of target species. Other topics mentioned by respondents were genetic diversity studies across the population, encounter probability with control devices, bait consumption rates, barriers to dispersal, and seasonal abundance of the food.

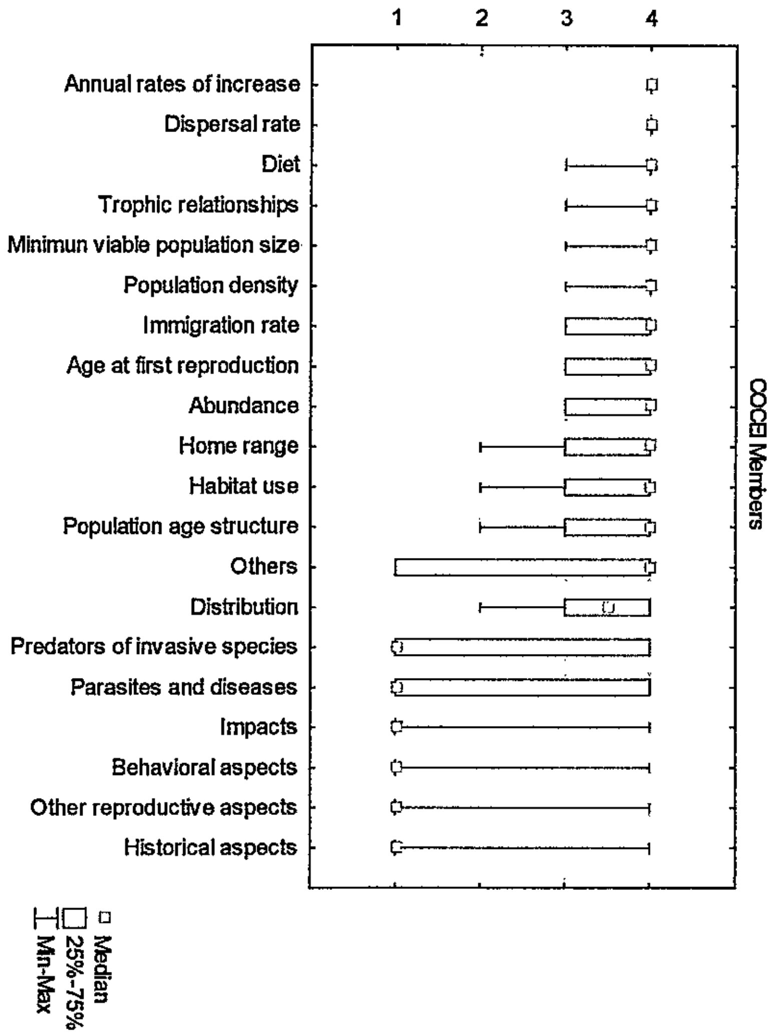

Figure 2. Importance given by COCEI members to different aspects of invasive mammal's biology for eradication purposes (1 = irrelevant, 2 = somewhat important, 3 = important and 4 = very important).

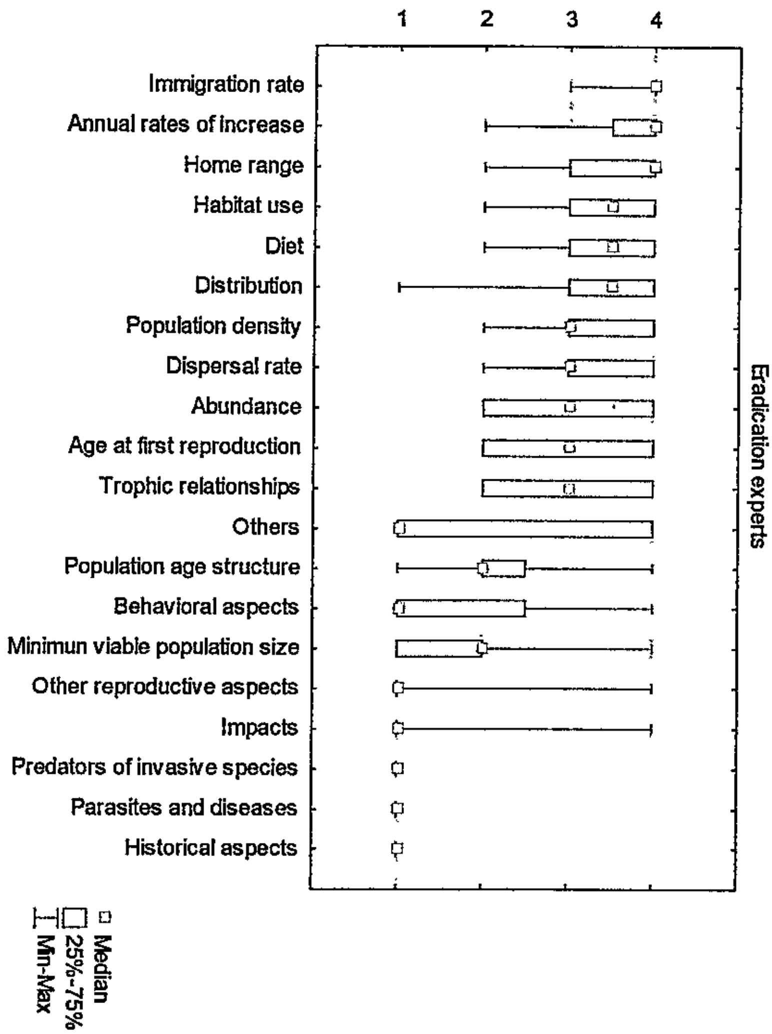

Figure 3. Importance given by eradication experts to different aspects of invasive mammal's biology for eradication purposes (1 = irrelevant, 2 = somewhat, 3 = important and 4 = very important).

Literature of invasive mammals

A total of 140 publications were found about thirteen invasive mammal species in Chile, spanning from 1885 to 2012 (Appendix 4). Some of the publications referred to more than one species, so that the number of cases analyzed totals 218. The most studied species was European rabbit with the 26.1% of cases, followed by European hare (12.8%), and American beaver (11.5%). The least studied species are muskrat and wild boar with 4.1% of cases each, followed by feral goat (3.2%), fallow deer (2.3%), and, finally, coatimundi (1.4%) (Fig. 4)

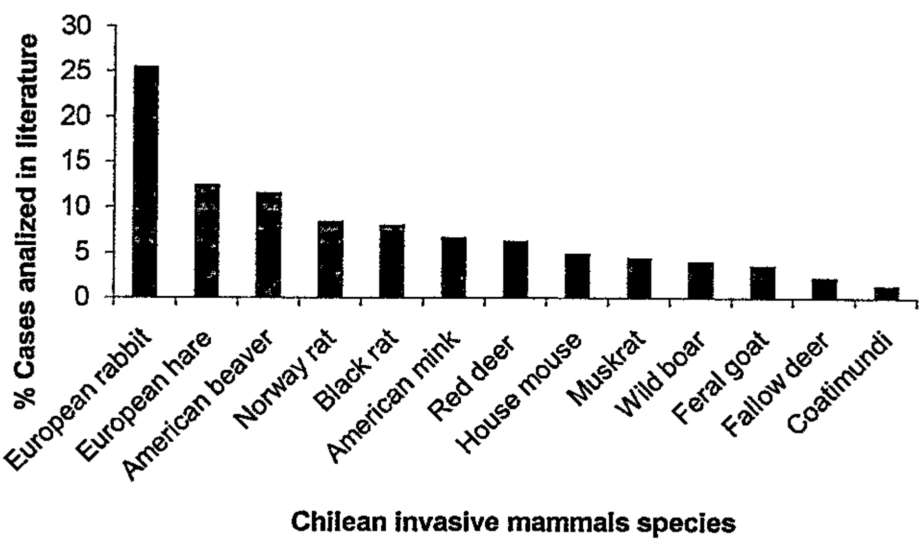

Figure 4. Percentage of cases analyzed per invasive mammal species.

The frequency of the topics covered by each species in literature is similar across all species (Kendall's W= 0.55; p <0,001). However, information addressed in literature was not correlated with the opinion of eradication experts about the most important biological information required for eradication goals (r_s= -0.28; p= 0.23). The most studied aspects were distribution (33%), followed by habitat use (21.6%), and diet (11%). Data about home range and dispersal rate were recorded in less than 2% of cases. Immigration rate and annual growth rate were not studied for any of the thirteen invasive mammal species in Chile. On the other hand, impacts of invasive species, considered of low importance for eradication program design, were studied in 17.4% of cases (Fig. 5).

For individual species, no significant correlation was found among the information contained in the articles and information requirements of the experts for eradication goals. Except for rabbits, which is negatively correlated (Table 3.)

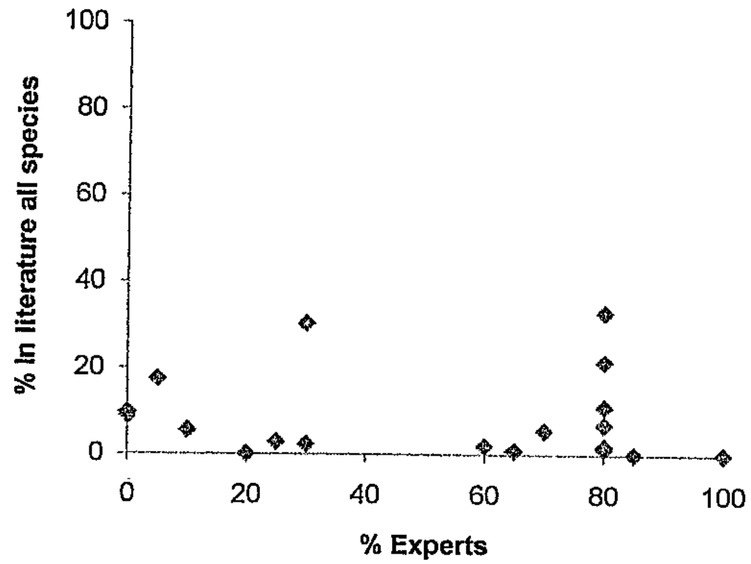

Figure 5. Scatter-plot of the importance given by experts to variables versus coverage percentage in literature for all species.

Table 3. Spearman's correlation between experts opinion about biological aspects relevant for eradication purposes with biological aspects addressed in the scientific literature for the thirteen invasive mammals.

Mammal species	r_s	*p*
American beaver	0.08	0.72
American mink	0.13	0.59
Black rat	0.06	0.80
Coatimundi	-0.26	0.25
European hare	-0.22	0.34
European rabbit	-0.44	0.05
Fallow deer	-0.02	0.92
Feral goat	-0.25	0.27
House mouse	0.05	0.83
Muskrat	-0.15	0.53
Norway rat	0.06	0.79
Red deer	0.04	0.86
Wild boar	0.00	0.99

American beaver (*Castor canadensis)*

Impacts were studied in 44% of publications (e.g., Anderson *et al.* 2006a; Arismendi *et al.* 2008; Baldini *et al.* 2008; Wallem *et al.* 2010), followed by reports on distribution in 24% of them (e.g., Anderson *et al.* 2006b; Skewes *et al.* 2006). Until recently it was thought that beavers were confined to Tierra del Fuego Island and the surroundings across the Beagle Channel, but in recent years they established on the Brunswick Peninsula, where they are starting to invade the southernmost part of the South American continent (Skewes *et al.* 2006). The least studied aspects were diet, dispersal rate, population age structure, and historical aspects in 4% of publications each. Other topics addressed were related to the management of this invasive species from the perspective technical, ethical or social (e.g., Haider & Jax, 2007; Schütler *et al.* 2011).

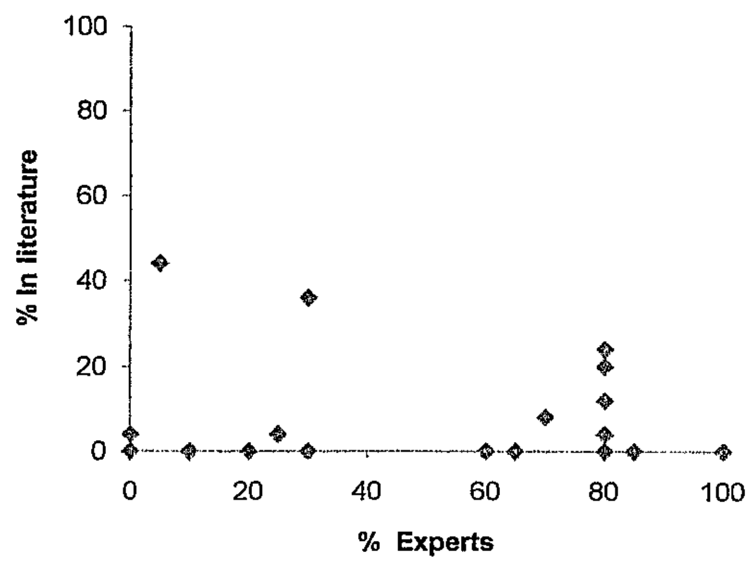

Figure 6. Scatter-plot of the importance given by experts to variables versus coverage percentage in literature of American beaver.

American mink (*Mustela vison*)

Diet was evaluated in 53.3% of publications. Some of these studies delve into the variation of the diet throughout the year, and also between habitats (e.g., Medina, 1997; Schütler *et al.* 2008; Ibarra *et al.* 2009). Distribution was the second aspect most studied with 33.3% of the articles. The species is widely distributed throughout southern Chile including Tierra del Fuego Island and adjacent archipelagos (Rozzi & Sherriffs, 2003, Anderson *et al.* 2006b; Sepúlveda *et al.* 2011). Trophic relationships (e.g., Medina, 1997), parasites and diseases (e.g., Sepúlveda *et al.* 2011), and historical aspects (e.g., Jaksic *et al.* 2002) were studied in 6.7% of cases.

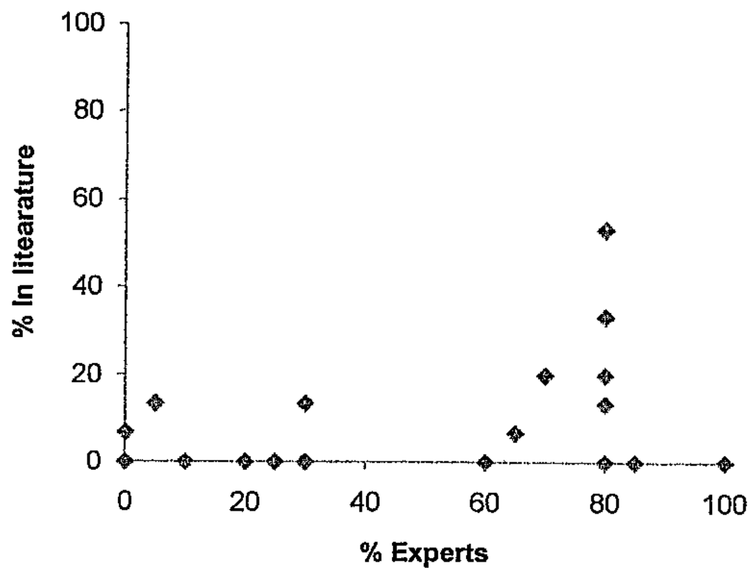

Figure 7. Scatter-plot of the importance given by experts to variables versus coverage percentage in literature of American mink.

Black rat (*Rattus rattus*)

Data on distribution were addressed in 52. 9% of articles (e.g., Schamberger & Fulk, 1974; Simonetti, 1983; Lobos *et al.* 2005), and habitat use in 24.9% of them (e.g., Lobos *et al.* 2005; Milstead *et al.* 2007). This species along with Norway rat occupy a variety of natural environments throughout Chilean mediterranean region (Lobos *et al.* 2005). Natural barriers to these invaders are northern desert regions, high altitudes, and the cold southern regions (Lobos *et al.* 2005). Scarcely studied were home range, population density, trophic relationships, reproductive aspects, and predators (e.g., Housse, 1953; Greer, 1965; Simonetti & Otaíza, 1982; González-Acuña *et al.* 2003; Lobos *et al.* 2005).

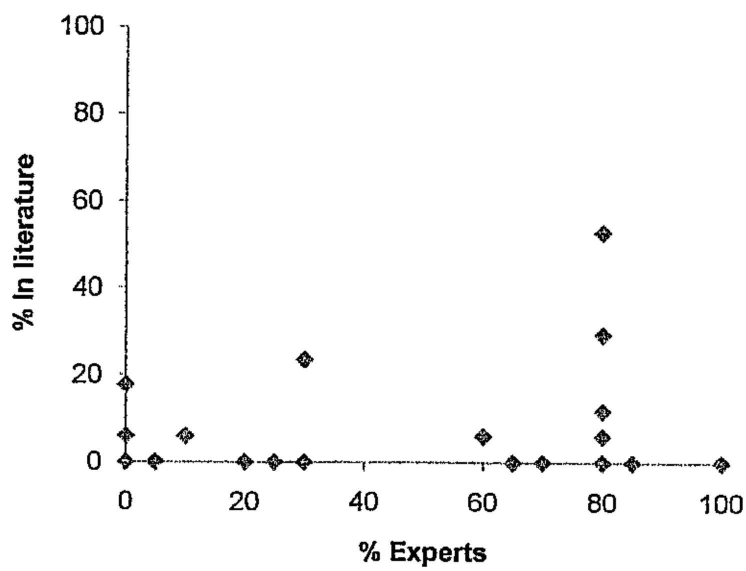

Figure 8. Scatter-plot of the importance given by experts to variables versus coverage percentage in literature of black rat.

Coatimundi (*Nasua nasua*)

Only three publications were found for this opportunistic carnivore introduced to Robinson Crusoe Island in the early 1930s. Information published was on distribution (e.g., Pine *et al.* 1979), impacts on an endemic and endangered hummingbird in Juan Fernández Archipelago (e.g., Colwell, 1989), historical aspects (e.g., Pine *et al.* 1979), and one article that reports on legal status (e.g., Iriarte & Jaksic, 1986).

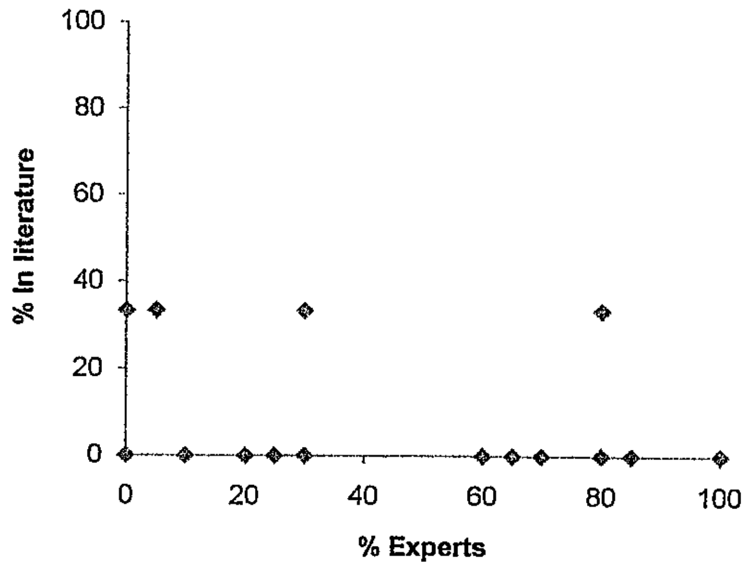

Figure 9. Scatter-plot of the importance given by experts to variables versus coverage percentage in literature of coatimundi.

European hare (*Lepus europaeus*)

Observations on its distribution were documented in 39.3% of articles (e.g., Greer, 1965; Pine *et al.* 1979; Johnson *et al.* 1990). This species is present in continental Chile from the Region III to Region XII, and its greatest abundances are recorded in Regions XI and XII (Jaksic *et al.* 2002). They have not yet arrived Chiloé Island, Tierra del Fuego Island, or the Juan Fernández Archipelago (Jaksic, 1998). Information on their predators was documented in 25% of publications. European hare is an important prey of native species such as puma (*Puma concolor*), black-chested eagle (*Geranoaetus melanoleucus*), Magellanic owl (*Bubo magellanicus*), and culpeo fox (*Pseudalopex culpaeus*) (e.g., Iriarte *et al.* 1990, 1991; Johnson & Franklin, 1994). Diet, abundance, trophic relationships, reproductive aspects, and parasites and diseases were less studied.

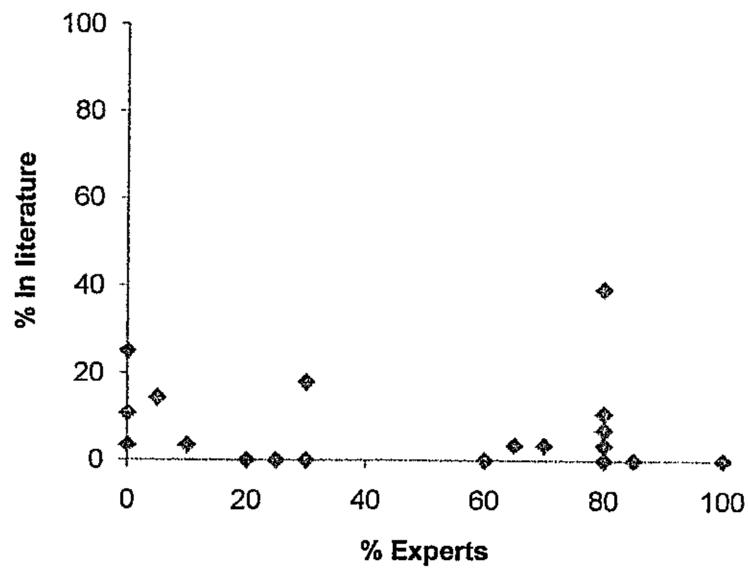

Figure 10. Scatter-plot of the importance given by experts to variables versus coverage percentage in literature of European hare.

European rabbit (*Oryctolagus cuniculus*)

Habitat use was studied in 26.3% of cases, which focused in central Chile (e.g., Simonetti & Fuentes, 1982; Simonetti, 1989). We found no studies of habitat use in Juan Fernandez Archipelago, Chilean Patagonia and Tierra del Fuego, where this species is also present. Impacts (e.g., Fuentes *et al.* 1983; Fernández & Saíz, 2007) and predators (e.g., Jaksic & Yáñez, 1980; Jaksic & Ostfeld, 1983) were documented in 19.2% of publications each. The least studied aspects were population density (e.g. Saíz & Ojeda, 1988) and age at first reproduction (e.g, Housse, 1953; Zunino & Vivar, 1985) in 3.5% each. Some publications discussed management issues in different regions invaded (e.g., Fuentes & Jaksic, 1980; Jaksic & Yañez, 1983; Saíz & Ojeda, 1988).

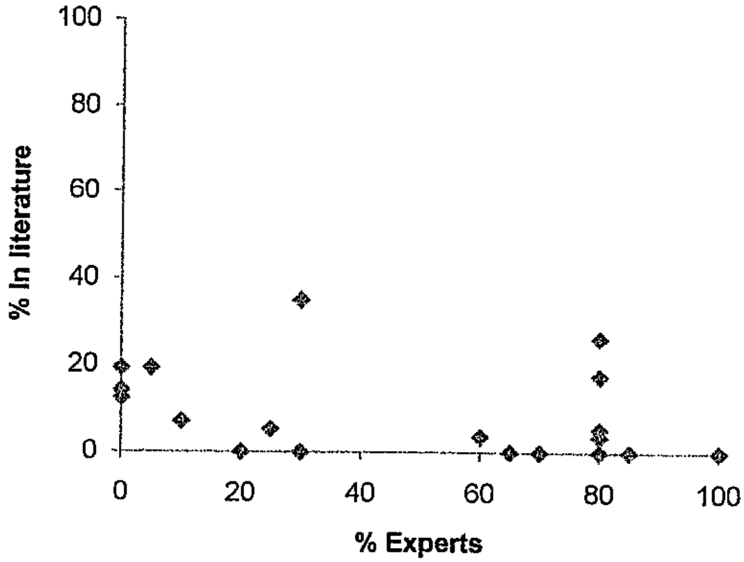

Figure 11. Scatter-plot of the importance given by experts to variables versus coverage percentage in literature of European rabbit.

Fallow deer (*Dama dama*)

Only five articles were found for this cervid. Distribution was studied in 60% of them (e.g., Schneider, 1946; Ortíz, 1991; Murúa, 1995), followed by habitat use in 40% (e.g., Schneider, 1946; Murúa, 1995). Currently the species is present in Regions IX, X, XI. Recently, had been taken to an enclosure on Chiloé Island, from where they escaped and have established themselves in the surrounding area (Flueck & Smith-Flueck, 2012). One of the articles is a complete study of the fallow deer biology (e.g., Eldrige, 1983). This article reports about home range, diet, abundance, population age structure, behavioral and reproductive aspects, and impacts.

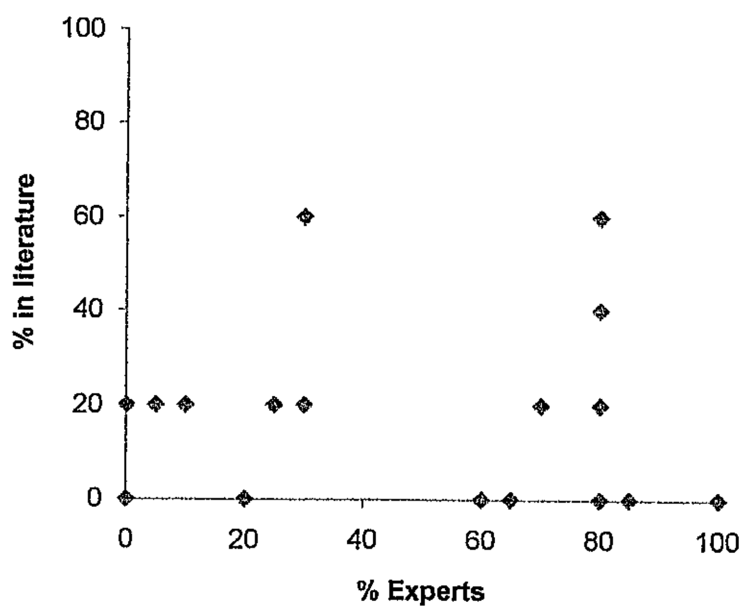

Figure 12. Scatter-plot of the importance given by experts to variables versus coverage percentage in literature of fallow deer.

Feral goat (*Capra hircus*)

The goat is a domestic animal throughout Chile, except in the Juan Fernández Archipelago, where it is found in a feral state and is considered a pest (Jaksic, 1998). Only seven articles were found for this species. Impacts are the most studied topic with 71.4% of the cases, but only one article addressed their effects in Juan Fernández (Colwell, 1989). Diet was reported in 28.6% of cases, and historical aspects and others in 14.3% of publications each.

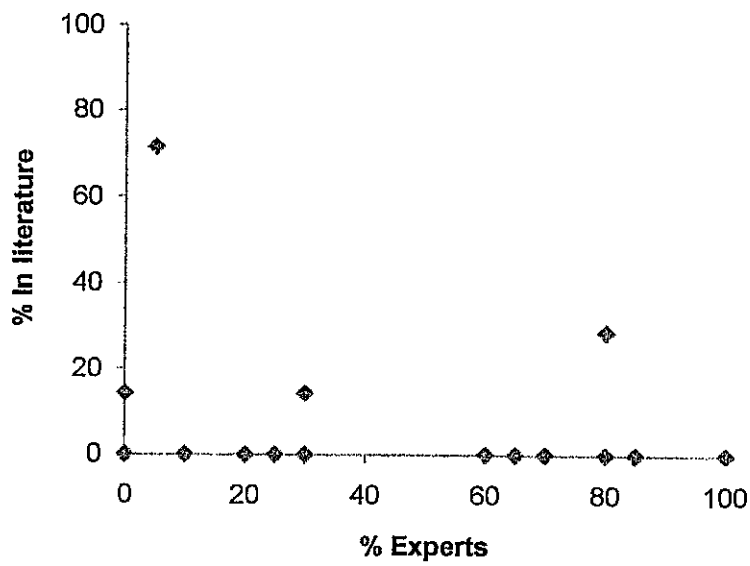

Figure 13. Scatter-plot of the importance given by experts to variables versus coverage percentage in literature of feral goat.

House mouse (*Mus musculus*)

Distribution data were found in 63.6% of articles (e.g., Greer, 1965; Péfaur *et al.* 1978; Lobos *et al.* 2005), and habitat use in 36.4% of them. This murine is strongly associated with human settlements, and only occasionally found in natural environments (Lobos *et al.* 2005). Only one study was found about parasites, which was conducted in Santiago, Chile (e.g.,Landaeta-Aqueveque *et al.* 2007).

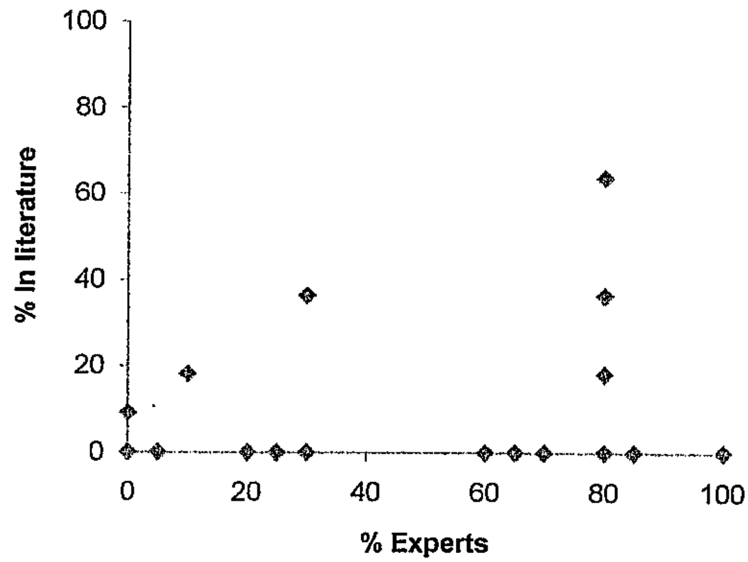

Figure 14. Scatter-plot of the importance given by experts to variables versus coverage percentage in literature of house mouse.

Muskrat (*Ondatra zibethicus* Linnaeus, 1758)

Observations on its distribution were documented in 66.7% of articles (e.g., Rosenmann, 1961). This species colonize Isla Grande of Tierra del Fuego and surrounding islands, and seems to be fully confined to these areas (Jaksic *et al.* 2002). Much less studied are habitat use (e.g., Sielfeld, 1977), historical aspects (e.g., Jaksic *et al.* 2002) and predators (e.g., Schütler *et al.* 2008). The muskrat is a main prey in the diet of mink in Tierra del Fuego, and could protect other native species fall prey to this predator opportunistic, but on the other hand represents a reliable source of food for mink (Schütler *et al.* 2008)

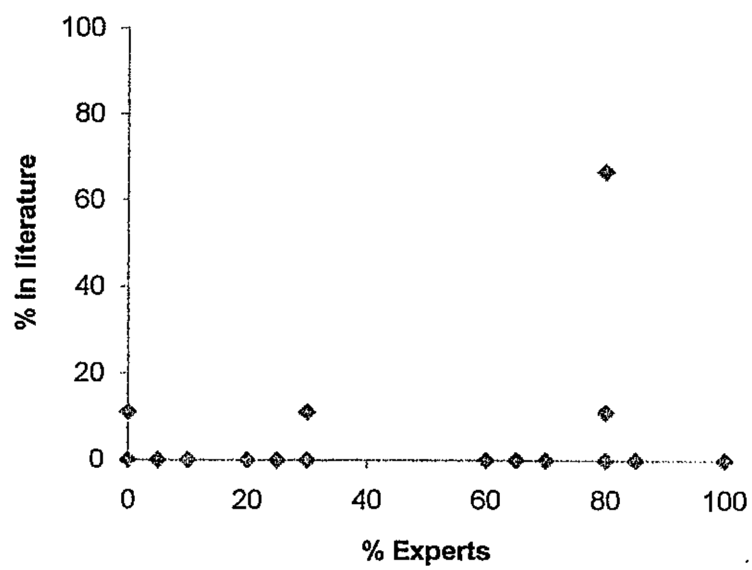

Figure 15. Scatter-plot of the importance given by experts to variables versus coverage percentage in literature of muskrat.

Norway rat (*Rattus norvegicus)*

Distribution was studied in 36.8% of articles (e.g., Lobos *et al.* 2005) and parasites and diseases in 26.3% of them (e.g., González-Acuña *et al.* 2003, 2005). Reports were also found about predation on intertidal organisms, and experimental studies to evaluate predation at Humboldt Penguin colonies in central Chile (Navarrete & Castilla, 1993; Simeone & Luna-Jorquera, 2012). The least studied in literature on this murine are population density, abundance, age at first reproduction, behavioral and reproductive aspects in 5.3% of publications each.

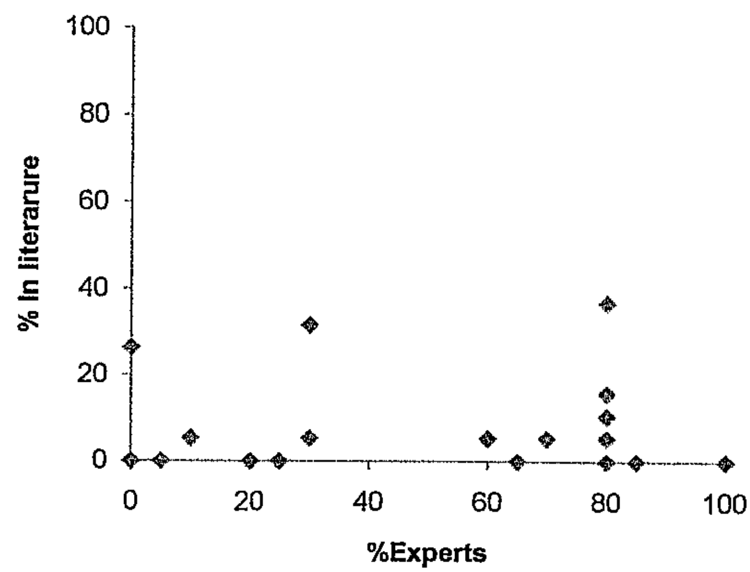

Figure 16. Scatter-plot of the importance given by experts to variables versus coverage percentage in literature of Norway rat.

Red deer (*Cervus elaphus*)

Distribution and habitat were documented in 38.5% and 30.8% of articles, respectively (e.g, Eldridge *et al.* 1980; Ramírez *et al.* 1981; Ortíz, 1991). This cervid is found in a feral state from Region VII to Region XI (Jaksic, 1998). On the other hand, captive enclosures represent high risks due to cases of escapees, which would provide source animals for feral populations (Flueck & Smith-Flueck, 2012). Population density, population age structure, and behavioral aspects were addressed in 7.7% of articles each (e.g., Eldridge, 1983).

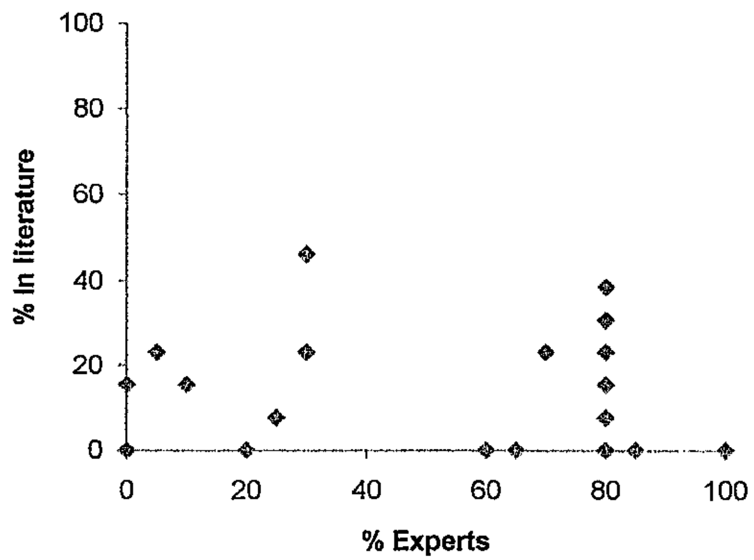

Figure 17. Scatter-plot of the importance given by experts to variables versus coverage percentage in literature of red deer.

Wild boar (*Sus scrofa)*

Data on distribution and habitat use were the most documented (e.g., Murúa 1995; Skewes *et al.* 2007). Currently, wild boar is present in entire Andean region from Region VIII to Region XI (Skewes *et al.* 2007), and also in Tierra del Fuego (Silva & Saavedra, 2008). Diet was studied in only one article (Skewes *et al.* 2007), and other study reports the wild boar as a recent prey of a native species, the puma (*Puma concolor),* in southern Chile (Skewes *et al.* 2012). Other topics were found in 44% of articles. Some of them relate to the management of wild boar farms in Chile and animal production (e.g., Skewes & Morales, 2006; Aravena & Skewes, 2007).

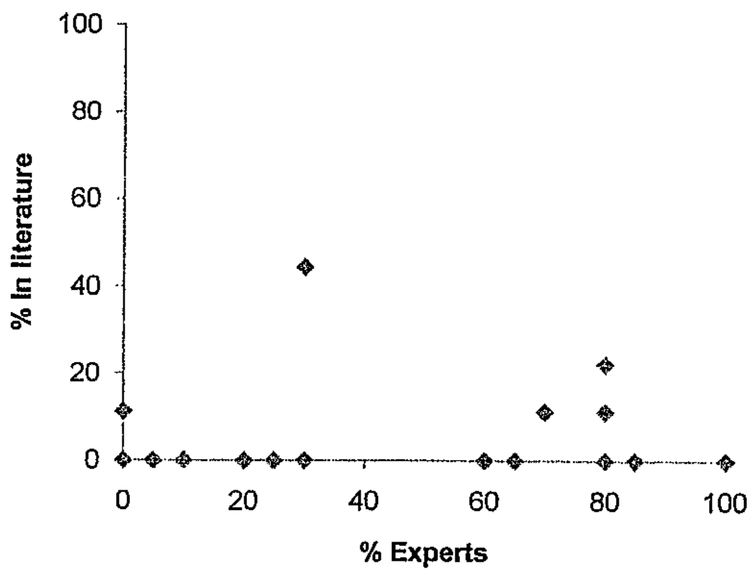

Figure 18. Scatter-plot of the importance given by experts to variables versus coverage percentage in literature of wild boar.

Validity of transfer biological information of target species

Regarding to the validity to transfer biological information of target species, 85% of eradication experts and 83% of COCEI members agreed that biological information of target species available at given place can be transferred only partially to other places where the species has been introduced in order to support eradication attempts. Some general information, such as age of first reproduction, could be transferred. However, many other aspects depend on the particular conditions of each system. Likewise, the effects of the removal must be addressed considering the unique ecological interactions that establish target species with other species present in the eradication environment.

DISCUSSION

Successful eradications can lead to significant effects in terms of recovery of native species and habitats (Genovesi, 2007), and in many cases are an essential prerequisite to restoring ecosystems. To meet the requirements for successful eradication, designing an eradication program should consider biology and ecology of target species. In this context, the expert consultation about the most important questions of target species biology for eradication goals provides an important opportunity to determine whether in Chile we have this information to implement potential eradication programs of mammals.

In general, rates of increases, immigration rates, population density, diet and aspects of spatial ecology of target species (e.g., home range, dispersal rate) should be carefully taken into account for planning eradication. Dispersal of target species and the feasibility of isolating the species within the eradication area are significant factors affecting success of eradication attempts (Usher, 1989). Species with low dispersal capacity and restricted distribution ranges may be easier to eradicate than those with high dispersal capacity and widely distributed (Valenzuela *et al.* 2013). For example, successful eradication of muskrats and nutria in Britain were attributed to low dispersal rates rather than to low rates of increase (Usher, 1986). For this reason the experts consider important a comprehensive study of dispersal of target species in its introduced range including dispersal rate from independent sources (immigration rate), local dispersion, dispersal periodicity, dispersal routes and barriers to dispersal. Other aspects incorporated by the experts are associated with the behavior of target species. For example, studies on the behavior from previous control or trials are very informative for eradication design and method development. If a proportion of the target population develops bait-shyness or trap aversion due to pre-eradication activities, the eradication is likely to fail if similar techniques are deployed (Cromarty *et al.* 2002). Breeding behavior such as behavior changes during the rut, pregnancy and nursing also be considered. For example, timing of the eradication should avoid the nursing period when females and young may have restricted home ranges (Barun *et al.* 2011).

Experts agree that information on the target species biology may be only partially transferred between two regions where the species is present. Although the information collected in other invaded areas is better than nothing, often there are important site differences. General factors (e.g., age at first reproduction) probably hold true across the range of invaded regions. However, factors as breading season, home range, and diet might show great variation depending on characteristics of the specific locality environment (e.g., tropical versus temperate, other species present, etc). We cannot use a "cookbook" (or standardized) approach to design an eradication program (G. Witmer pers. comm.). Each project must judge the usefulness of existing information and weigh the risks of not collecting data specific to the site against the costs of collecting it (K. Broome pers. comm).

The study of invasive mammals in Chile does not address the information needs to implement potential eradication programs. We suggest that future research is oriented to study dispersion, growth rates, distribution, population density, home ranges and habitat use. On the other hand, ecological interactions with native and other exotic species should be considered in management programs. They can play a major role in the final outcomes of eradication (Genovesi, 2007), and ignoring them can lead to undesired effects, particularly in highly invaded systems. For example, eradication of invasive herbivores might cause a population explosion of exotic plants, or removal of invasive prey might cause invasive introduced predators consume more native species (Courchamp *et al.* 2011). Multiple eradications carry out sequentially or simultaneously are widely considered to avoid these undesired effects. For example, in Tierra del Fuego Archipelago, where the muskrat is part of mink's diet, it has been suggested the simultaneous management of both species (Silva & Saavedra, 2008). Similarly, in Robinson Crusoe, Juan Fernández

Archipelago, has been recommended multiple eradicating rodents, rabbits and feral cats (Saunders *et al.* 2011).

Furthermore, not only is there a lack of information for potential programs to eradicate invasive mammals, but also the study of invasive mammals in Chile is quite uneven. It is worrisome that for some species like muskrat, wild boar, feral goats, and coatimundi were found little information, especially considering that they have invaded sites of great ecological value such as the Juan Fernández Archipelago, National Park and World Biosphere Reserve, and Tierra del Fuego Archipelago, one of the last places on Earth thay may still be considered wild (Silva & Saavedra, 2008). There is only anecdotal evidence of the impacts of coatimundi and feral goat in Juan Fernández, and there were not found studies of its biology and ecology in this place. On the other hand, wild boar is considered one of the most harmful invasive species in the world (Lowe et al. 2004), but its biology have been poorly documented (e.g., Skewes *et al.* 2007; Skewes *et al.* 2012). Muskrat publications focus mainly on observations of its presence/ absence at Tierra del Fuego Archipelago. This species, along with beaver, is among the most widely distributed in the southernmost region, and is one of the 'most potentially harmful' in the area (Silva & Saavedra, 2008), but little is known of its natural history.

While Chile has historically opted for a strategy of prevention and control rather than eradication in the management of their invasive mammal species (e.g., Jaksic & Yañez, 1983; Saíz & Ojeda, 1988; Skewes *et al.* 1999), this situation may be reversing. Currently, the governments of Chile and Argentina are conducting pilot studies to eradicate the beaver throughout its range in Patagonia (Menvielle *et al.* 2010), a very ambitious project, and in Juan Fernández Archipelago there has been a feasibility study that recommended eradication of species such as rabbits, feral cat, goat and coatimundi (Saunders *et al.* 2011). These projects could open the way to position eradication as a conservation tool in Chile, and so protect other island systems. They are also valuable models of cooperation and exchange of knowledge between different countries with the common purpose of protecting the global biodiversity. Advances in eradication field in the world are overcoming increasing challenges, such as include large islands, inhabited islands, multiple invaders eradications, and even eradication on the continent (e.g., Speedy *et al.* 2007) with numerous benefits for biodiversity and human welfare. We hope that these experiences can be replicated also in Chile, but for this is mandatory that scientific research responds to the information needs to guide effective eradication programs. On the other hand, it is important to note that decisions regarding invasive species management require the involvement of the general public, as well as authorities (Valenzuela *et al.* 2013). Sometimes, invasive species eradication is desirable from an ecological perspective and feasible from a technical standpoint but if the species is valued by society, then its removal should be carefully studied. If we really want to reverse the present trends of biodiversity loss, it is urgent that we perform concrete actions to manage our invasive species, and where possible eradicate, this should be a priority.

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APPENDIX 1

SURVEY

BIOLOGICAL INFORMATION FOR INVASIVE MAMMAL ERADICATION

1. How important do you consider this biological information about species population ecology to successfully eradicate invasive mammal? (Mark "x" your choice in the)

   a. Abundance
      ☐ Not at all important ☐ Somewhat ☐ Important ☐ Very

   b. Age at first reproduction
      ☐ Not at all important ☐ Somewhat ☐ Important ☐ Very

   c. Annual rates of increase
      ☐ Not at all important ☐ Somewhat ☐ Important ☐ Very

   d. Immigration rate
      ☐ Not at all important ☐ Somewhat ☐ Important ☐ Very

   e. Minimum viable population size
      ☐ Not at all important ☐ Somewhat ☐ Important ☐ Very

   f. Population age structure
      ☐ Not at all important ☐ Somewhat ☐ Important ☐ Very

   g. Population density
      ☐ Not at all important ☐ Somewhat ☐ Important ☐ Very

   Do you have any comment?

   ____

2. How important do you consider this biological information about species spatial ecology to successfully eradicate invasive mammal?

a. Dispersal rate
☐ Not at all important ☐ Somewhat ☐ Important ☐ Very

b. Distribution
☐ Not at all important ☐ Somewhat ☐ Important ☐ Very

c. Habitat use
☐ Not at all important ☐ Somewhat ☐ Important ☐ Very

d. Home range
☐ Not at all important ☐ Somewhat ☐ Important ☐ Very

Do you have any comment?

____

3. How important do you consider this biological information about species trophic ecology to successfully eradicate invasive mammal?

a. Diet
☐ Not at all important ☐ Somewhat ☐ Important ☐ Very

b. Trophic relationships
☐ Not at all important ☐ Somewhat ☐ Important ☐ Very

Do you have any comment?

____

4. Do you consider there is another important or very important aspect of the biology of invasive mammal species not included above? Which one?

____

5. Have you participated in an eradication program of some of the following species?

- ☐ American beaver (*Castor canadensis*)
- ☐ American mink (*Mustela vison*)
- ☐ Black rat (*Rattus rattus*)
- ☐ Coatimundi (*Nasua nasua*)
- ☐ European rabbits (*Oryctolagus cuniculus*)
- ☐ European hares (*Lepus europaeus*)
- ☐ Fallow deer (*Dama dama*)
- ☐ Feral cat (*Felis catus*)
- ☐ Feral goat (*Capra hircus*)
- ☐ House mice (*Mus musculus*)
- ☐ Muskrat (*Ondatra zibethicus*)
- ☐ Norway rat (*Rattus norvegicus*)
- ☐ Red deer (*Cervus elaphus*)
- ☐ Wild boar (*Sus scrofa*)
- ☐ Other mammal: ______________________________
- ☐ Other taxon : ______________________________

6. If biological information were available for a given species at a given place, do you consider such information is transferable to other places were the species has been introduced in order to support eradication attempts?

____

APPENDIX 2

A. List of eradication experts that responded to the survey.

	Name	Institution
1	Algar, David	Department of Environment and Conservation, Wildlife Research Centre. Wanneroo, Australia.
2	Broome, Keith	Department of Conservation, Hamilton, New Zealand.
3	Campbell, Karl	Island Conservation, Santa Cruz, California, U.S.A.
4	Cowan, Phil	Landcare Research, Palmerston North, New Zealand.
5	Donlan, Josh	Advanced Conservation Strategies, Midway, U.S.A. & Department of Ecology and Evolutionary Biology, Cornell University, Ithaca, New York, U.S.A.
6	Griffiths, Richard	Department of Conservation, Auckland Area Office, Devonport, Auckland, New Zealand.
7	Hanson, Chad	Island Conservation, Santa Cruz, California, U.S.A.
8	Macdonald, Norm	Native Range, Inc., Ventura, California, U.S.A.
9	McClelland, Peter	Department of Conservation. Invercargill, New Zealand.
10	Norbury, Grant	Landcare Research, Alexandra, New Zealand.
11	Parkes, John	Landcare Research, New Zealand
12	Pierce, Ray	EcoOceania Pty Ltd, Speewah, Queensland, Australia.
13	Robinson, Sue	Wildlife Management Branch, Department of Primary Industries, Parks, Water and Environment, Hobart, Tasmania, Australia.
14	Russell, J.	School of Biological Sciences and Department of Statistics, University of Auckland, Auckland, New Zealand.
15	Samaniego, Araceli	Grupo de Ecología y Conservación de Islas, A.C., Ensenada, Baja California, México
16	Saunders, Alan	Landcare Research, Hamilton, New Zealand.
17	Springer, Keith	Tasmania Parks and Wildlife Service, Moonah, Tasmania, Australia.
18	Veitch, C.R.	48 Manse Road, Papakura, New Zealand.
19	Wegman, Alex	Island Conservation, Santa Cruz, California, U.S.A.
20	Witmer, Gary	USDA/APHIS/WS National Wildlife Research Center. Fort Collins, Colorado, U.S.A.

B. List of eradication experts that not respond to the survey.

	Name	Institution
1	Aguirre, Alfonso	Grupo de Ecología y Conservación de Islas, A.C., Ensenada, Baja California, México.
2	Brown, Derek	128b Redwood St. Blenheim, New Zealand.
3	Buckelev, Stacey	Island Conservation, Santa Cruz, California, U.S.A.
4	Carrion, Victor	Galápagos National Park Service, Islas Galápagos, Ecuador.
5	Cruz, Felipe	Galápagos National Park Service, Galápagos, & Charles Darwin Foundation, Quito, Ecuador.
6	Harper, Grant	Charles Darwin Foundation, Quito, Ecuador, & Rotoiti Nature Recovery Project, Department of Conservation, New Zealand.
7	Howald, Greeg	Island Conservation Canada, Vancouver, British Columbia, Canada.
8	Luna-Mendoza, Luciana	Grupo de Ecología y Conservación de Islas, A.C. Ensenada, Baja California, México.
9	Murphy, Elaine	Research & Development Group, Department of Conservation, Christchurch, New Zealand, & Invasive Animals Cooperative Research Centre, University of Canberra, Canberra, Australia.
10	Roy, Sugoto	Central Science Lab, Sand Hutton, York, England.
11	Torr, Nick	64 Mokonui Street, Te Anau, New Zealand.
12	Wilkinson, Ian	Office of Environment and Heritage, New South Wales, Australia.

APPENDIX 3

A. List of COCEI members that responded to the survey.

	Name	Institution
1	Báez, Pedro	Section Hydrobiology. National Museum of Natural History.
2	Díaz, Miguel	Department of Conservation Biodiversity. Forest Service (CONAF, in Spanish).
3	González, Cecilia	Division of Natural Resources Protection. Agriculture and Livestock Service (SAG, in Spanish).
4	Guerreo, Sofía	Division of Natural Resources and Biodiversity. Ministry of Environment (MMA, in Spanish).
5	Lembeye, Georgina	Department of Aquaculture. Undersecretary of Fisheries (SUBPESCA, in Spanish).
6	Núñez, Denisse	Department of Forest Plantations. Forest Service (CONAF, in Spanish).

B. List of COCEI members that not respond to the survey.

	Name	Institution
1	Agüero, Teresa	Department of Agricultural Policies. Office of Studies and Agricultural Policies (ODEPA, in Spanish). Ministry of Agriculture.
2	Baeza Ignacio	Department Space Security and Environment. Chile Air Force (FACH, in Spanish).
3	Barrientos, Alejandro	Undersecretary of Fisheries (SUBPESCA, in Spanish).
4	Biscupovich, Susana	Division of Agricultural and Forest Protection. Agriculture and Livestock Service (SAG, in Spanish).
5	Bobadilla, Eliana*	Division of Agricultural and Forest Protection. Agriculture and Livestock Service (SAG, in Spanish).
6	Céspedes, Nancy*	Department of Natural Resources. Directorate of Environment and Maritime Affairs. Ministry of Foreign Affairs.
7	García, Marcelo	Fisheries Department. Undersecretary of Fisheries (SUBPESCA, in Spanish).

8	González, Álvaro	Division of ---- Protection. Agriculture and Livestock Service (SAG, in Spanish).
9	Guerra, Jorge	Undersecretary of Fisheries (SUBPESCA, in Spanish).
10	Guajardo, Daniela	Department of Aquaculture. Undersecretary of Fisheries (SUBPESCA, in Spanish).
11	Gutiérrez, Cristián	National Headquarters of Crimes Against the Environment and Cultural Heritage (JENAMA, in Spanish). Chilean Investigative Police (PDI, in Spanish).
12	Ibáñez, Lilian	Division of Agricultural and Forest Protection. Agriculture and Livestock Service (SAG, in Spanish).
13	Íbañez, Pamela	Agriculture and Livestock Service (SAG, in Spanish).
14	Jorquera, Guillermo	Department of Customs Intelligence. National Service Costums.
15	Malhue, Gonzalo	Department Fisheries Management. National Service of Fisheries (SERNAPESCA, in Spanish).
16	Martínez, Carlos*	Preservation Aquatic Environment and Combating Pollution. Directorate General of Maritime Territory and Merchant Marine (DIRECTEMAR, in Spanish).
17	Medina, Juvenal	Direction of Planning. O.S.5 Department. Carabineros of Chile.
18	Medina, Patricio*	National Service of Fisheries (SERNAPESCA, in Spanish).
19	Miranda, Leyla*	Directorate General of Maritime Territory and Merchant Marine (DIRECTEMAR, in Spanish).
20	Morales, Nino	Carabineros of Chile.
21	Moyano, María Iris	National Service of Fisheries (SERNAPESCA, in Spanish).
22	Núñez, Leonardo	Department Fisheries Management. National Service of Fisheries (SERNAPESCA, in Spanish).
23	Palominos, José*	National Headquarters of Crimes Against the Environment and Cultural Heritage (JENAMA, in Spanish). Chilean Investigative Police (PDI, in Spanish).

24	Romo, Maricel	Agriculture and Livestock Service (SAG, in Spanish).
25	Tala, Charif	Division of Natural Resources and Biodiversity. Ministry of Environment (MMA, in Spanish).
26	Trivelli, Miguel Ángel	Division of Protection of Renewable Natural Resources. Agriculture and Livestock Service (SAG, in Spanish).
27	Zamorano, Eugenio	Department of Aquaculture. Undersecretary of Fisheries (SUBPESCA, in Spanish).

* Responds that it is not their area of research.

APPENDIX 4

Literature review

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