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Ecological effects and distribution of invasive non-native mammals on the Canary Islands

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ABSTRACT

1. The ecological effects and distribution of 13 invasive non-native mammal species on the Canary Islands are reviewed.

2. Six species, representing six different taxonomic orders, are widely distributed and live on all seven main islands of the Canarian Archipelago: *Felis catus*, *Capra hircus*, *Rattus rattus*, *Rattus norvegicus*, *Mus domesticus* and *Oryctolagus cuniculus*. *Atelerix algirus* is found on four islands while six further species are present on only one island: *Crocidura russula*, *Suncus etruscus*, *Rousettus egyptiacus*, *Ovis gmelini*, *Ammotragus lervia* and *Atlantoxerus getulus*.

3. Five species have an omnivorous diet, four are herbivorous, two insectivorous, one frugivorous and one carnivorous. The ecological effects and damage caused by these species in the natural habitats of the Canaries are similar to those in other insular regions. To our knowledge, the effects of two species, *A. lervia* (herbivorous) and *A. getulus* (omnivorous), are as yet unreported for other insular environments.

4. Two of the most pernicious effects caused by invasive non-native mammal species in the Canaries consist of predation by feral cats of the three giant lizard species present in the western islands, but especially *Gallotia gomerana*, which is now on the verge of extinction; and the damage that the four species of herbivores cause to the endemic flora of the archipelago.

Keywords: Canarian Archipelago, introduced mammals, invasive species, island ecological effects

INTRODUCTION

The invasion of ecosystems by exotic species, originally facilitated by man, is considered to be one of the most important causes of biodiversity loss (De Vos, Manville & Van Gelder, 1956; Vitousek *et al*., 1997; Groombridge & Jenkins, 2000; McNeely *et al*., 2001), especially on islands (Veitch & Clout, 2002; Courchamp, Chapuis & Pascal, 2003). There is a general movement towards the identification and measurement of the threat of particular non-indigenous species to native species populations, communities and ecosystems (Parker *et al*., 1999). The measurement of this impact will enable us to distinguish invaders that cause minor effects from those with profound effects in order to prioritize management efforts in invaded sites and those facing potential invasion.

Insular environments are often characterized by the presence of a high rate of endemism of species and/or subspecies as the result of evolutionary isolation. Many of island species

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have evolved in the absence of strong ecological influences such as competition, herbivory, parasitism or predation (Stone, Snell & Snell, 1994). Furthermore, islands are frequently characterized by specific or distinctive ecological processes, such as mutualisms in seed dispersal systems, that have the potential to be disrupted by the actions of non-native mammals that sometimes become highly invasive (Traveset & Santamaría, 2004).

In 2001, the IUCN published a list of the 100 worst invasive species, which included 14 mammalian species (Lowe, Browne & Boudjelas, 2001), five of which are present in all the seven main Canary Islands: the domestic cat *Felis catus*, the goat *Capra hircus*, the black rat *Rattus rattus*, the house mouse *Mus domesticus* and the European rabbit *Oryctolagus cuniculus*. Unfortunately, all of these species are considered to be mainly responsible for the greater part of the damage caused in insular ecosystems worldwide (Courchamp *et al*., 2003).

With regard to the Canarian Archipelago, these islands harbour about 3672 terrestrial endemic species (39% of the animals, 21% of the plants and 6% of the fungi). Of a total of 13 328 terrestrial species, 1434 have been introduced by man, 47% are invertebrates, 46% plants, 4% fungi and 3% are vertebrates (Martín Esquivel *et al*., 2005). Of some 20 mammal species that live in the Canaries, 13 can be considered to have been introduced by man and have become established; they belong to six different taxonomic orders. Due to their variable ecology and geographical origin, they exhibit different patterns of habitat selection and responses to novel environments, producing different environmental effects. The existence of a variety of habitats in the Canaries, mainly as a function of altitude and orientation, offers a range of possibilities for settlement. These habitats are organized and described in some detail below. The main ecological effects produced on the habitats and the native species are related to the modification of food webs, both by direct predation, as prey of other native predators or by disruption of mutualistic phenomena.

Here, we have first reviewed information on the incidence and distribution of non-native mammals in the Canary Islands. We have compiled data from published and grey literature, mainly contained in internal or unpublished reports, or personally communicated by scientists and organizations involved in nature conservation, covering the archipelago. The main aim of this contribution is to compile disparate information on the ecological effects of Canarian non-native mammals as a practical tool for scientists and conservationists both in this archipelago and in other insular regions worldwide.

THE CANARY ISLANDS

The Canarian Archipelago is of volcanic origin and is located about 100 km from the northwest coast of Africa. It is comprised of seven main islands and several islets (Fig. 1), the highest of which is Tenerife (Pico Teide: 3718 m a.s.l.) and the lowest Lanzarote, only 671 m a.s.l. Tenerife is also the largest island (2036 km^2), while the smallest is El Hierro (278 km^2). The climate in the Canaries varies according to altitude. Mean temperature and annual precipitation range from about 21°C and 100–300 mm, respectively, in coastal zones, to about 9°C and 500–800 mm, respectively, at higher altitudes. These factors are very important because they have a direct effect on the vegetation. Lanzarote and Fuerteventura, the eastern islands, are low in altitude and highly influenced by dry winds from the nearby Sahara Desert, the vegetation being characterized by a dry xerophytic shrub that only appears in the lowlands of the higher central and western islands of the Canaries (Gran Canaria, Tenerife, La Gomera, El Hierro and La Palma) and is characterized by species of the genus *Euphorbia*. The vegetation of the Canaries is clearly distributed as a function of altitude and orientation, including other more humid forest habitats. Potential vegetation includes a temperate forest, located at 300–550 m a.s.l., composed of a mixed wood of *Dracaena draco* (Agavaceae),

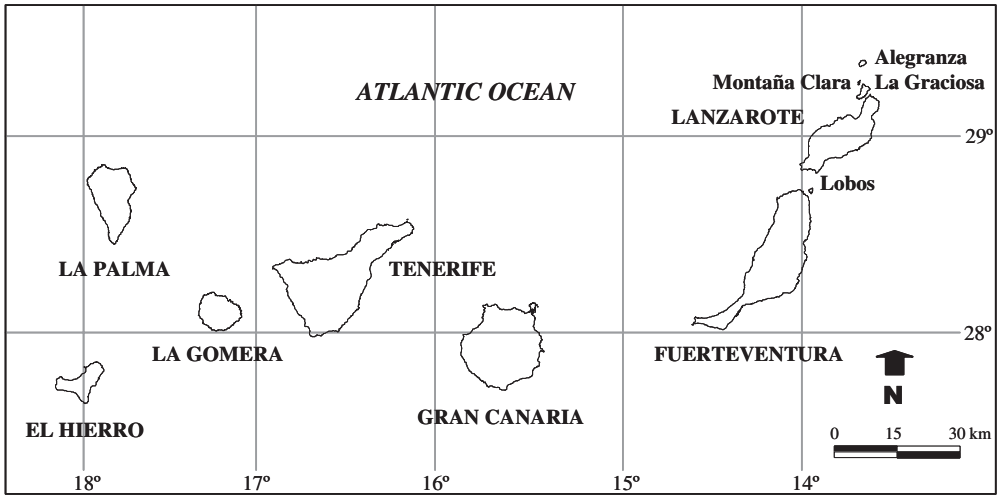

Fig. 1. The Canarian Archipelago.

Phoenix canariensis (Arecaceae), *Juniperus turbinata* (Cupressaceae), etc. Between 550 and 1300 m appears the most humid habitat, the laurel forest, which is constituted by about 23 tree species, several of them endemic. Important species are *Laurus novocanariensis* and *Persea indica* (Lauraceae), *Myrica faya* (Myricaceae) and *Erica arborea* (Ericaceae), which form a dense evergreen forest. Following in altitude is a drier monospecific pine forest (1300–2000 m) of the endemic *Pinus canariensis* (Pinaceae), a generally sparse plant formation. Finally, above 2000 m a.s.l., the vegetation is characterized by sparse leguminous shrubs, such as *Spartocytisus supranubius* and *Adenocarpus viscosus* (Fabaceae), and other species of genus *Descurainia* (Brassicaceae) or *Pterocephalus* (Dipsacaceae). This last habitat is of great importance because of its large component of endemic plants.

DISTRIBUTION AND ORIGIN OF INVASIVE NON-NATIVE MAMMALS

A total of 13 mammal species have been introduced by man to the Canary Islands and have become established in the wild (Table 1). These species are drawn from six taxonomic orders, and their geographical origins are located in Europe, Africa and Asia.

The number of species per island varies, ranging between 10 in Tenerife and six in the smallest islands of La Gomera and El Hierro (Table 1). Six are present in all the main seven islands of the archipelago: the domestic cat *Felis catus*, the goat *Capra hircus*, the black rat *Rattus rattus*, the brown rat *Rattus norvegicus*, the house mouse *Mus domesticus* and the European rabbit *Oryctolagus cuniculus*, while another six species are present in one only: the great white-toothed shrew *Crocidura russula*, the pygmy white-toothed shrew *Suncus etruscus*, the Egyptian fruit bat *Rousettus egyptiacus*, the European mouflon *Ovis gmelini*, the Barbary sheep *Ammotragus lervia* and the Barbary ground squirrel *Atlantoxerus getulus*; the Algerian hedgehog *Atelerix algirus* is present in the central and eastern islands. Only two species were introduced in pre-Hispanic times: *C. hircus* (≈2500 year ago; Navarro, Martín & Rodríguez, 1990) and possibly *M. domesticus* (Carrascosa & López-Martínez, 1988), while another (*A. algirus*) was introduced just before the 20th century. The introduction of five species presumably took place around or after the 15th century and was related to the European conquest of the islands. Another four species were introduced during the 1960s–70s and, most recently, *R. egyptiacus*, around the year 2000 (Table 1). More specific information on

Table 1. List and distribution of invasive non-native mammal species present in the Canary Islands

		Distribution								
Species	Order	Lanzarote	Fuerteventura	Gran Canaria	Tenerife	La Gomera	La Palma	El Hierro	Native range	Introduction date
Atelerix algirus	Insectivora	×	×	×	×				North Africa	1892
Crocidura russula	Insectivora			×					South-west Europe and North Africa	≥15th century
Suncus etruscus	Insectivora				×				North Africa and South Europe to Central and South-west Asia	≈1970s–80s
Rousettus egyptiacus	Chiroptera				×				Africa and Asia	≈2000
Felis catus	Carnivora	×	×	×	×	×	×	×	Europe, Asia and Africa	≥15th century
Capra hircus	Artiodactyla	×	×	×	×	×	×	×	Asia	≈2000 years BP
Ovis gmelini	Artiodactyla				×				Corsica, Sardinia, Cyprus and the Near East	1971
Ammotragus lervia	Artiodactyla						×		North Africa	1972
Atlantoxerus getulus	Rodentia		×						North-west Africa	1965 (1970s)
Rattus rattus	Rodentia	×	×	×	×	×	×	×	South-east Asia	≥15th century
Rattus norvegicus	Rodentia	×	×	×	×	×	×	×	Asia (China)	≥18th century
Mus domesticus	Rodentia	×	×	×	×	×	×	×	West and South Europe, Asia and North Africa	≈1000–1700 years BP
Oryctolagus cuniculus	Lagomorpha	×	×	×	×	×	×	×	Europe (Iberian Peninsula) and North-west Africa	≥15th century
All species		7	8	8	10	6	7	6		

distribution, in 10×10 km squares, can be obtained in the 'Atlas of Spanish Mammals' (Palomo & Gisbert, 2002).

ECOLOGICAL EFFECTS OF THE SPECIES

Greater white-toothed shrew *Crocidura russula*

Restricted to agricultural areas and small remaining pockets of laurel forest in the north-eastern part of Gran Canaria, this shrew was considered until recently to be endemic to this island (*Crocidura osorio*; Molina & Hutterer, 1989). However, molecular studies and the lack of fossil evidence have found no support for this taxon (Molina *et al*., 2003; Vogel, Cosson & López-Jurado, 2003). Although the diet of this species in continental populations is based on invertebrates, mainly insects (Churchfield, 1984), no specific information in this regard has been found in Gran Canaria. However, it has been reported that the food spectrum of the endemic *Crocidura canariensis*, distributed in the eastern islands and islets, is based on insects but can include the small endemic lizard *Gallotia atlantica*, preyed upon by secreting venom (López-Jurado & Mateo, 1996).

Pygmy white-toothed shrew *Suncus etruscus*

In the Canary Islands, this species was first cited by Martín, Hutterer & Corbet (1984) for Tenerife, where it mainly occupies different habitats in the north part of the island. The precise date of introduction is unknown and its diet has not been studied although it is probably based on small invertebrates, as occurs in continental areas (López-Fuster, 2002). It is also interesting to note that the Canaries harbour a rich endemic invertebrate fauna, represented mainly by the class Insecta, of which there are 1307 endemic species in Tenerife (Martín Esquivel *et al*., 2005), pointing to the potential effects that this shrew can have on this particular animal group.

Algerian hedgehog *Atelerix algirus*

This species is relatively abundant in the eastern islands of Lanzarote and Fuerteventura, where semiarid habitats are largely represented. In the central islands of Gran Canaria and Tenerife it is mainly linked to agricultural habitats although it shows a wide environmental and altitudinal distribution (Hutterer, 1983). Unfortunately, practically no ecological information is available on this species in the Canaries. However, Nogales (1985), analysing 30 droppings collected at the edges of the Canarian pine forest of Inagua (SW Gran Canaria), reported that its diet was basically composed of Coleoptera. In this analysis seeds from the endemic plant *Plocama pendula* (Rubiaceae) were also found (Barquín, Nogales & Wildpret, 1986), providing evidence that this animal causes disruptions in some native seed dispersal systems in which seeds are commonly dispersed by lizards and birds (Nogales *et al*., 1999; Valido, 1999). According to our observations in agricultural zones of Tenerife, hedgehogs consume large amounts of Diplopoda.

Few data have been reported on the ecological effects of *A. algirus* in other insular environments, but in the Balearic Islands this hedgehog predates upon small invertebrates and occasionally on small vertebrates (mainly geckos) (Alcover, 2002). In a related species, the west European hedgehog *Erinaceus europaeus* is an important predator of wader eggs in the Western Isles of Scotland (Jackson & Green, 2000; Jackson, 2001). The high vulnerability of ground-nesting birds could be an important factor for some species that breed in the semiarid habitats of the eastern Canaries (von Thanner, 1913) and open habitats of the central islands (Lorenzo *et al*., 2001). Thus, this species has the potential to cause damage to endemic invertebrate populations.

Black rat *Rattus rattus*

It is widespread throughout the seven main islands of the archipelago, occupying practically every habitat although probably in different densities. This species probably became established in the Canary Islands with the arrival of the European conquistadors in the 15th century. The effects of *R. rattus* on fruits, seeds, leaves and shoots of several plants species from the laurel forest have been recorded in different studies (Bañares & Barquín, 1982; Delgado, 1997; Delgado García, 2000, 2002; Godoy, 2001; Salvande, Mulet & Gómez, 2001; Gómez & Fernández, 2003; Salvande, Gómez & Fernández, 2003), which revealed that rats might affect plant regeneration and hence the structure and composition of the laurel forest. However, *R. rattus* also has a detrimental effect on native fauna, being a predator of birds, especially their eggs and chicks (Martín *et al*., 1990; Tucker & Heath, 1994; Delgado, Arévalo & Fernández-Palacios, 2005). Hernández, Martín & Nogales (1999) installed cameras beside artificial nests of the endemic pigeons *Columba bollii* and *Columba junoniae* in the laurel forest, recording that rats were the main predator of their eggs, causing a decrease in breeding success.

Brown rat *Rattus norvegicus*

It has spread to all the islands of the Canaries but is absent from the islets. It mainly inhabits towns and villages where it damages crops (see Pérez Padrón & Miralles Ciscar, 1974). It also occupies some rural areas where it has also probably influenced the ecological degradation of the Canarian natural ecosystems. In this regard, the two rat species present in the Canaries have been reported as being mainly responsible for the restriction of different seabird species to the small islets in this archipelago (Martín *et al*., 1989; Martín, 2001). Moreover, the Brown rat has probably contributed to the decline of the population of the endangered endemic subspecies of passerine *Calandrella rufescens rufescens* (Lorenzo *et al*., 2001).

Rats are commensal species that have been accidentally introduced to many islands worldwide, having colonized at least 82% of the 123 major island groups (Atkinson, 1985). The two species present in the Canaries show different ecological habitat selection, *R. rattus* being more abundant in wild habitats and *R. norvegicus* in more anthropogenic environments. Therefore, it seems possible that the general effect of the former species in the Canaries has been worse than that of the latter. *Rattus norvegicus* has terrestrial habits and has been considered in other islands to be responsible for the rarefaction and frequent local extinction of land- and seabirds (Møller, 1983; Moors, 1985; Courchamp *et al*., 2003). However, *R. rattus* exhibits more arboreal habits and its effect is noteworthy on vertebrate forest species, especially birds (Lever, 1994). Furthermore, in New Zealand several cases of bird extinction have been reported where this last species played an active role (Bell, 1978). Rats cause damage to animals but they also consume the roots, bark, stems, leaves, seeds and fruits of many native and endemic plant species. Therefore, these rodents affect the dynamics of island habitats, and can cause great harm when they concentrate their action on plant species that characterize a particular habitat. Perhaps some of the best documented cases have occurred in the Galapagos Islands, where the damage produced by *R. rattus* on the vegetation has been considered to be partly responsible for the extinction of four species of endemic rice rats belonging to the genus *Oryzomys* (Brosset, 1963).

Barbary ground squirrel *Atlantoxerus getulus*

Widely distributed throughout the semidesert habitats of Fuerteventura, where it was kept as a pet species in 1965, several animals were released or escaped during the 1970s (Machado, 1979). Also, 15 individuals were caught in some localities of Gran Canaria between 1996 and

1998, probably due to both accidental and voluntary introductions (Calabuig, 1999). However, an established feral population has not been confirmed in this island.

Machado & Domínguez (1982) estimated the Fuerteventura population between 200 000 and 300 000 squirrels (2–296 individuals/ha). These authors comment that despite the lack of information on factors such as depredation or competition with other species, population control may depend on intrinsic factors. Some cases have been observed of predation by the Eurasian kestrel *Falco tinnunculus* (D. Trujillo, personal communication) and the common buzzard *Buteo buteo* (M. Nogales, personal observation and V. Quilis, personal communication) and its carcasses form a part of Egyptian vulture *Neophron percnopterus* diet (Medina, 1999). In this respect, Gangoso & Darias (2004) recorded the presence of this species as prey in a percentage near to 40% of 147 *B. buteo* pellets analysed.

Studies carried out on diet by direct observation and analysis of gut contents indicated that this rodent shows an omnivorous diet with a strong plant component (75%; Machado & Domínguez, 1982), including *Nicotiana glauca* (Solanaceae), *Salsola vermiculata* (Chenopodiaceae), *Emex spinosa* (Polygonaceae), *Scilla* sp. and *Asphodelus* sp. (Liliaceae). In the animal component, the presence of terrestrial molluscs is noteworthy, a group represented by 13 endemic species in Fuerteventura (Alonso & Ibáñez, 2005). In relation to its effect on the endemic flora, five endangered plant species are possibly consumed by this rodent (Bañares *et al*., 2003). This squirrel is also involved in the disruption of the seed dispersal system of the Macaronesian endemic plant *Rubia fruticosa* (Rubiaceae) in Fuerteventura (Nogales *et al*., 2005).

House mouse *Mus domesticus*

The house mouse occurs on all the main islands and islets of the archipelago, with the exception of Montaña Clara. The presence of this species in the Canaries has been associated with the arrival of pre-Hispanic inhabitants between approximately 1000 and 1700 years ago (Carrascosa & López-Martínez, 1988). However, palaeontological information indicates that *M. domesticus* could have colonized the island earlier than man (Castillo, Martín-González & Coello, 2001). Currently, this rodent is a commensal species closely related to humanized habitats that lives mainly near agricultural fields avoiding the interior of the laurel forest (Contreras, 1988; Delgado, Arévalo & Fernández-Palacios, 2001). Although it is omnivorous, the species feeds mainly on seeds and small invertebrates. Michaux, López-Martínez & Hernández-Pacheco (1996) have suggested that the appearance of *M. domesticus* in the Canaries may have influenced the gradual decrease of the lava mouse *Malpaisomys insularis*, an extinct endemic Muridae from Fuerteventura and Lanzarote islands. Furthermore, Boye *et al*. (1992) considered that the house mouse possibly transmitted a disease to the native mouse, which contributed to the extinction of the latter.

Little is known about the direct effect of mice on natural island habitats, but they likely prey on invertebrates (Le Roux *et al*., 2002) and seabirds (Ogilvie Grant, 1896; Moors & Atkinson, 1984), having some negative influence on the vegetation (Burger & Gochfeld, 1994). Furthermore, in Thevenard Island (Australia), *M. domesticus* competes with a rare species of short-tailed mouse *Leggadina lakedownensis* (Moro, 2001).

Domestic cat *Felis catus*

This species is present in most island groups worldwide including those oceanic islands most isolated from the mainland (Fitzgerald, 1988). It is probable that the Canary Islands constitute one of the archipelagos where the diet of feral cats has been better studied, covering all the main habitats represented and previously described. Currently it is known that this

generalist carnivore preys actively on introduced mammals (mainly rabbits) in the five main habitats of this archipelago (see review of Nogales & Medina, 1996; Medina, García & Nogales, 2006). However, other prey acquires a greater importance in other habitats, as occurs with the reptiles (lizards) in the high mountain, where one of the highest rates of reptile captures in the world has been recorded (Nogales *et al*., 1990). Also, the black rat is a frequent prey in the laurel forest, while birds are often taken in forest habitats (Santana, Martín & Nogales, 1986; Nogales *et al*., 1988; Nogales & Medina, 1996). Feral cats have been considered to be mainly responsible for the decline of several giant endemic lizards (genus *Gallotia*) in the Canaries, such as *Gallotia simonyi* (García-Márquez, López-Jurado & Mateo, 1997; Rodríguez-Domínguez, Coello & Castillo, 1998), *Gallotia intermedia* (Hernández, Nogales & Martín, 2000; Rando & López, 2001) and *Gallotia gomerana* (Valido *et al*., 2000; Nogales *et al*., 2001). Furthermore, one of the most pernicious effects caused by this carnivore has been upon seabirds, being probably involved in the decline and local extinction of small Procellariiformes populations in the main islands of the Canaries (Martín *et al*., 1989; Ardura & Calabuig, 1993), and limiting their current distribution to uninhabited islets and inaccessible cliffs (Martín *et al*., 1989). No species has yet been declared extinct in the Canaries because of introduced mammals. However, Martín (2001) has commented that the combined effect of cats and rats may have contributed to the extinction of the endemic Canarian oystercatcher *Haematopus meadewaldoi*.

Apart from the direct predation effect on native and endemic vertebrate species, feral cats act as secondary seed dispersers of at least six native and two introduced plants through consumption of frugivorous lizards of genus *Gallotia* both in the coastal habitat and temperate forest (Nogales, Medina & Valido, 1996). These authors also comment that their relatively recent presence in the islands, and the active seed dispersal carried out by lizards and birds, suggest that natural regeneration of these native plants does not depend on seed movements due to this carnivore. Furthermore, another more complex ecological effect has been linked to the extinction of giant lizards in the Canaries, in turn mainly imputed to feral cats. Such is the case of the Canarian endemism *Neochamaelea pulverulenta* (Cneoraceae), whose smaller seeds are suboptimally dispersed by the current population of smaller lizards, seemingly important for the survival of this plant species (Valido, 1999).

It is well known that this species was introduced to several islands to control rodent and rabbit populations (Lever, 1994). A combination of factors such as the lack of antipredator behaviour of island preys and the catholic diet of feral cats has had a devastating effect. This opportunistic predator (Fitzgerald, 1988) has been directly responsible for numerous island extinctions of mammals (Mellink, 1992; Tershy *et al*., 2002), reptiles (Iverson, 1978; Mitchell *et al*., 2002) and birds (Jehl & Parks, 1983; Lever, 1994; Veitch, 2001) worldwide. Due to the dramatic effects caused in island biotas, intensive eradication campaigns have been successfully carried out in at least 48 islands worldwide (Nogales *et al*., 2004).

Egyptian fruit bat *Rousettus egyptiacus*

Individuals of this species have been present since 1992 in two Tenerife zoos, located in the northern and southern lowlands of the island, respectively. It is suspected that several animals escaped in 2000 resulting in two different populations in the surrounding areas (Trujillo, 2003). According to this author, their diet is comprised of plant species of ornamental and agricultural interest, mainly fruits produced by *Phoenix canariensis* and *Phoenix dactylifera* (Arecaceae), *Persea americana* (Lauraceae), *Musa* cf. *acuminata* (Musaceae), *Ficus nitida* (Moraceae) and *Syzygium jambos* (Myrtaceae). According to Trujillo (2003) the presence of this bat in Tenerife may become an important environmental problem due to its great

adaptability and potential to spread all over the island, ultimately affecting fruit trees and even fruits from the native laurel forest where the two Canarian endemic pigeons (*Columba bollii* and *C. junoniae*) are present. In other areas, *R. egyptiacus* is known to be a selective seed disperser (Izhaki, Korine & Arad, 1995) that has caused important damage to fruit crops in Israel (Makin & Mendelssohn, 1985) and South Africa (Jacobsen & Du Plessis, 1976).

Goat *Capra hircus*

In the last 30 years the number of feral goats has decreased due to economic and social changes, and also to farming practices. However, some animals still remain on the steep slopes of the islands, where a high number of endemic plant species survive. This herbivore has been present in practically all habitats represented in the Canaries, affecting different plants in each. The negative effects produced by goats on the native vegetation have been reported by some authors since the middle of the last century, both in the high mountain and the Canarian pine forest habitats (Sventenius, 1946; Ceballos & Ortuño, 1976, respectively). Furthermore, their negative effects on the natural habitats have been pointed out as one of the most important factors facilitating the establishment of other ruderal and introduced plants (Kunkel, 1980; Dickson, Rodríguez & Machado, 1987).

Despite the presence of goats in the Canaries since pre-Hispanic times, there is scant information on the effect of this species on the natural environments of the Canaries. In this regard, Nogales, Marrero & Hernández (1992) studied the impact on the vegetation of the pine forest of Pajonales, Ojeda and Inagua, in Gran Canaria, recording the consumption of at least 24 plant species, 14 (58.3%) of which are endemic to this island, 7 (29.2%) to the Canaries, 1 (4.2%) to the Macaronesian Islands and another 2 (8.3%) that showed a wider distribution.

It is interesting to remember that the Canaries harbour 524 endemic vascular plant species (Martín Esquivel *et al*., 2005), of which 167 are listed in the 'Atlas and Red List of the Threatened Vascular Flora of Spain' (Bañares *et al*., 2003), and that at least 16% of them are consumed in any stage by non-native wild herbivores. In the case of the feral goats, this species has been responsible for the rarefaction and extinction of several endemic plants in other insular regions (Turbott, 1948; Coblentz, 1978; Parkes, 1993). Furthermore, they have also produced other negative indirect ecological effects on islands such as defoliation and erosion, affecting the breeding burrows of seabirds (McChesney & Tershy, 1998). Goats have also been cited as being responsible for the impoverishment of the vertebrate and invertebrate fauna because of overgrazing in some islands (Hamman, 1975; Brook, 2002).

European mouflon *Ovis gmelini*

A herd of 11 animals was released in 1971 in the Teide National Park (Tenerife Island) for hunting purposes. Currently, its distribution area is about 371 km^2 (18% of the island), which includes the National Park and other surrounding protected areas (Rodríguez Luengo, 1993). According to this author, its population was estimated at about 400 individuals. This high mountain area is host to a great proportion of endemic plants and many of them are currently threatened. Of the 168 taxa of vascular plants registered, 58 are Canarian endemics (35%), 33 (20%) are endemic to Tenerife and 12 (7%) are restricted exclusively to the National Park (Wildpret de la Torre & Martín Osorio, 2004).

The studies carried out of the mouflon's diet, performed by analysing gut content and faeces, showed that it includes 38 plant taxa: 33 phanerogamous and five cryptogamous. The most widely consumed plants, in order of importance, were *Spartocytisus supranubius* (Fabaceae), *Descurainia bourgeauana* (Brassicaceae), *Pterocephalus lasiospermus* (Dipsa-

caceae) when feeding on the high mountain shrub; and *Carlina xeranthemoides* (Compositae), *Pinus canariensis* (Pinaceae) and *Chamaecytisus proliferus* (Fabaceae) when feeding in the pine forest (Rodríguez Luengo, 1993). Of a total of 28 species of vascular plants identified, 14 were Canarian endemisms and 12 of them were exclusive to Tenerife. Moreover, the mouflon may have a negative effect on another 35 endemic and threatened plant species present in its distribution area (Rodríguez Luengo, 1993). For more detailed information see studies by Rodríguez, Rodríguez & Ramos (1988), Rodríguez Luengo, González Mancebo & Rodríguez Piñero (1990) and Alfayate & Rodríguez-Luengo, 1991).

Park managers also reported a negative impact on the populations of the following threatened endemic species: *Stemmacantha cynaroides* (Compositae), *Silene nocteolens* (Caryophyllaceae), *Helianthemum juliae* (Cistaceae) and *Cerastium sventenii* (Caryophyllaceae) (Durbán, 2003). *Stemmacantha cynaroides* has been classified as 'critically endangered' in the 'Atlas and Red List of the Threatened Vascular Flora of Spain' (Marrero, Carqué & Bañares, 2003) and as 'endangered' in the Spanish National Catalogue of Endangered Species; its population declining dramatically in recent years as a result of depredation by introduced herbivores (mouflons and rabbits) (Carqué *et al*., 2003) to fewer than 170 individuals growing exclusively in this National Park.

Ovis gmelini has also been introduced in several archipelagos such as Hawaii or Kerguelen. The ecological effects of this species follow the same harmful pattern on Tenerife as on Mauna Kea Volcano (Hawaii), also a zone rich in endemic plants, where the feeding and herding habits of feral sheep and mouflons have had a remarkable ecological effect on its particular flora (Giffin, 1979; Beldfield & Pratt, 2002). On Houte Island (Kerguelen) the combined effect of sheep and mouflons has eliminated or threatens several endemic plants by grazing and trampling (Chapuis, Boussés & Barnaud, 1994).

Barbary sheep *Ammotragus lervia*

For hunting purposes, a herd of 16 sheep were released into La Caldera de Taburiente National Park (La Palma Island) in 1972, an area with a high proportion of endemic and endangered plant species. Currently, the species range extends to at least 70 km^2 and its population was estimated to consist of 200–250 individuals at the beginning of the 1990s (Palomares Martínez, 1999). It mainly occupies pine forest and high mountain shrub. From analysis of the stomach contents of wild animals captured in autumn (1986–87), a total of 41 plant taxa were recorded, 21 of which were endemics at distinct biogeographical levels. The most significant plants in its diet were *Cistus symphytifolius* (Cistaceae), *Teline stenopetala* and *Adenocarpus viscosus* (Fabaceae) and *Pinus canariensis* (Pinaceae) (Rodríguez Piñero & Rodríguez Luengo, 1992). Gómez Campo (1996) considered that this species could be a potential threat for at least 10 more plant species of high scientific interest.

European rabbit *Oryctolagus cuniculus*

Rabbits were brought to the Canaries during the conquest of the archipelago in the 15th century (De Abreu Galindo, 1977) and although data on their abundance are limited (Cabrera Rodríguez, 1998; Martín, Marrero & Nogales, 2003), the species presently occupies all the habitats of the main islands, being also present in the main islets of Lobos, La Graciosa and Alegranza, but have been eradicated from Montaña Clara (Martín *et al*., 2002).

Despite the potential interest of studying the impact of this herbivore on the flora of the different habitats of this archipelago, only specific contributions to rabbit diet have been made in some xeric habitats of Alegranza (Martín, 1999; Martín & Marrero, 1999; Marrero & Martín, 2000; Martín *et al*., 2003); in this islet rabbits selected certain plant species (especially

of the family Chenopodiaceae) (Martín *et al*., 2003). Lastly, mutualistic interactions with the Canarian endemic plant *Plocama pendula* (Rubiaceae) have been described by Nogales, Valido & Medina (1995) in coastal habitats of Tenerife.

The European rabbit has been successfully introduced to more than 800 islands and is one of the most widely distributed animal species (Flux & Fullagar, 1992). The ecological effect of this species on islands has been one of the worse known, directly affecting numerous native and endemic plants and indirectly their associated fauna (Cheylan, 1984; Chapuis *et al*., 1995). Although its indirect effect on the invertebrate fauna has not been studied in depth (see Grayson & Hassall, 1985), it has been considered to be one of the main agents responsible for the decline and extinction of several vertebrate species due to the significant impact caused on their habitats (North, Bullock & Dulloo, 1994). One example could be that produced on the burrows of some seabird species, which can lead to colony desertion (Gillham, 1963; Bell, 1995). Two of the most devastating environmental effects caused by rabbits have been described in Round Island (Mauritius) (Bullock, 1977) and Laysan (Hawaiian chain islands) (Atkinson, 1989).

DISCUSSION

In order to prioritize management efforts, and according to current knowledge, feral cats and introduced herbivores are clearly having the worst impact on the endemic biota of the Canary Islands. Feral cats are believed to be the main factor threatening the endangered giant endemic lizards: *Gallotia simonyi* and *G. intermedia* and the critically endangered *G. gomerana.* Invasive non-native herbivores (European rabbit, European mouflon, barbary sheep and goat) are considered to be a threat for about 27 endangered or critically endangered endemic plant species (Bañares *et al*., 2003). According to the ecological impacts caused by these mammals in the Canary Islands, they exert a negative impact similar to those previously described in other insular areas.

With regard to the pygmy white-toothed shrew *S. etruscus*, the greater white-toothed shrew *C. russula,* the house mouse *M. domesticus* and the Algerian hedgehog *A. algirus*, further research is clearly required in order to evaluate their ecology and impact on the islands' ecosystems.

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