Impact of Non-native Mammalian Herbivores on Insular Plant Communities in the Canary and Balearic Islands

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Abstract

Biological invasions are a major cause of loss of biodiversity worldwide, particularly on islands. Introduced mammalian herbivores are among the most threatening of all invasive species, especially goats [*Capra hircus* (Linnaeus, 1758)], sheep [*Ovis orientalis aries* (Linnaeus, 1758)], mouflon (*Ovis orientalis musimon* [Pallas, 1762)], Barbary sheep [*Ammotragus lervia* (Pallas, 1777)], and rabbits [*Oryctolagus cuniculus* (Linnaeus, 1758)]. The vulnerability of insular plant communities, especially the endemic flora, is strongly influenced by their historic (and present) herbivory context, within which these introduced herbivores have played a key role. The effects of the introduction of mammals such as goats and rabbits are difficult to elucidate, as their introductions occurred thousands (or hundreds) of years ago and data on the previous status of the plant communities are not available. However, the present-day impacts of both of these herbivores on insular plant communities have been intensively studied. Herbivory can reduce the distribution area and constrain insular endemic species to inaccessible areas such as cliffs or islets, which impoverishes the original insular ecosystems and changes their species composition. Moreover, the

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negative effects of these species on the insular native flora have led to the development of eradication and control programmes on many islands, with the aim to recover and protect native plants. Coordination between policymakers, managers, researchers, hunters and society is crucial in order to identify efficient solutions to protect and restore insular plant communities, effectively manage hunting activities and optimally limit the effects of introduced mammals.

6.1 Overview of Introduced Mammalian Herbivores on Islands

The establishment and expansion of invasive species are one of the most significant drivers of global change (Lenzner et al. 2020; Bello-Rodríguez et al. 2021), and these impacts are especially dramatic on islands where native species have often evolved in the absence of strong competition, herbivory, parasitism or predation (Courchamp et al. 2003). In particular, the introduction of exotic herbivores has provided evidence of profound changes in island ecosystems (Courchamp et al. 2003) and the degradation impact can remain for hundreds or thousands of years until the herbivores are eradicated (Chapuis et al. 2004; Garzón-Machado et al. 2010; Velamazán et al. 2017).

Goats, sheep and rabbits are considered huge threats to the conservation of insular biodiversity when they become feral in natural areas (Cubas et al. 2019; Mayol et al. 2017). The negative effects of these feral livestock on insular plant communities and endemic flora, such as predation of endangered species, impact on demographical structure or propagation of alien species, among others, have been intensively studied by several authors since the middle of the last decade (Sventenius 1946; Ceballos and Ortuño 1951; Nogales et al. 1992; Salgado-Luarte et al. 2019), but information on how ecosystems respond to their impact remains largely unresolved in many systems. For instance, effective regeneration of some trees and shrubs in some arid Australian ecosystems is suppressed in favour of the establishment of alien plants that are adapted to herbivory (Cooke 2012). Notably, amongst all introduced mammalian herbivores, goats and rabbits are included in the Top 100 world's worst invasive alien species list published by the International Union for Nature Conservation (IUCN) (Lowe et al. 2004) and their eradication is considered a key factor for ecological restoration around the globe (Priddel et al. 2000; Donlan et al. 2002; Bried et al. 2009; Capizzi 2020; Rita et al. 2022). The impact of introduced mammalian herbivores on insular vegetation, especially endemic plant species, varies depending on their palatability, resistance and defence strategies, and their ecological distribution, among other factors (Cubas et al. 2019; Capó 2021). These impacts become especially harmful when they severely feed upon narrow or endangered species (Carqué et al. 2004; Velamazán et al. 2017), leading in some cases to local or regional extinctions. For example, in regions such as Australia, introduced mammalian herbivores can locally eliminate all of the seeds of native shrubs and shift the herbaceous composition, even at low herbivore densities (Lange and Graham 1983; Bird et al. 2012).

Here, we present a review of the literature about the impact of introduced mammalian herbivores in two insular systems, namely the Canary and Balearic Archipelagos. We seek to elucidate these impacts relative to historical (pre-introduction) by describing communities of extinct herbivore paleofauna, as well as by providing a detailed analysis of how and when introduced mammalian herbivores arrived in these archipelagos and what are their impacts on insular plant communities and concretely on threatened species. In doing so, we also examine differences and similarities between systems in introduced herbivore impacts and potential explanatory factors (from geographical origin to ecosystem variation). Finally, we also present perspectives on how to advance future multidisciplinary research needed to achieve effective solutions for island ecosystem management and conservation.

6.2 Native Herbivore Paleofauna of the Studied Insular Systems

Knowledge on the origin of islands is essential to understand the processes that mediated the evolution of plant-herbivore interactions and therefore the vulnerability or capacity of native plant species to defend themselves against introduced herbivores. Generally, islands are classified into two types depending on their origin: oceanic, that is, islands that emerged through the surfacing of submarine folds due to geological pressure; and continental, that is, islands that originated by tectonic plate movements that fragmented and isolated the terrestrial surface (Rosenbaum et al. 2002).

Oceanic islands represent 5% of the terrestrial surface of Earth and are considered one of the most important refuges for endemic species per unit area (Kreft et al. 2008). In fact, a staggering 25% of the entire endemic flora is located on oceanic islands (Fernández-Palacios 2004). At the same time, they are also one of the most threatened areas of the world and have suffered 80% of all-known species extinctions since the year 1500 aC (Ricketts et al. 2005). In the case of the Canary Islands, an example of this type of island, fossils of a variety of native reptiles and micromammals have been found, such as tortoises (*Geochelone* spp.) from the Pliocene (5.3–2.6 Mya) (López-Jurado and Mateo 1993) and more recent fossils from the Holocene, such as giant lizards (*Gallotia* spp.) (Castillo et al. 1994), an unknown snake (*Boidae*) (Barahona et al. 1998), as well as micromammals such as a native mouse [*Malpaisomys insularis* (Hutterer, López-Martínez & Michaux 1988)] (Hutterer et al. 1988) and giant rats (*Canariomys* spp.) (Crusafont-Pairo and Petter 1964). Overall, however, this system has historically been characterized by the absence of ungulates, with the exception of a bovid (NAME) during the last 5 million years, which was also present in the Balearic Islands. Therefore, the island origins of the Balearic and Canary Archipelagos—and thus the evolution of their flora—were driven by two very different ecological scenarios. Thus, the ideas about the impact of introduced mammalian herbivores on oceanic (Canary Islands) and continental

(Balearic Islands) islands presented throughout this chapter must be interpreted within the context of their different biogeographic origins and processes.

In contrast, continental islands can preserve well-established ecosystems that were present on the continent at the time of fragmentation. After fragmentation and isolation, these newly isolated communities followed their own line of evolution under insularity. Many fossil records from the Plio-Pleistocene period (5.3–0.01 Mya) confirm the existence of endemic insular mammalian herbivores on the continental islands of the Mediterranean Basin, ranging from micromammals (Vogel and Sofianidou 1996) to artiodactyls (Croft et al. 2006; Bover et al. 2010). However, all of these species became extinct before the Holocene, probably due to abrupt climatic change or as a result of the arrival of humans to the islands (Bover et al. 2016). The Balearic islands represent a system of this type, for which fossil records of mammalian herbivores have been dated back to the Holocene 4035 ± 32 years BP (Bover et al. 2016), followed by more abundant records dated after the Messinian salt crisis caused by the closure of the Strait of Gibraltar and the drying of the Mediterranean Sea (5.9–5.3 Mya) (Krijgsman et al. 1999). During the salt crisis, the Balearic Islands were still connected to the continent, which allowed the transfer of new herbivores. The genus *Myotragus* spp., which represents small artiodactyls, arrived and established on the island of Mallorca at this time, becoming one of the most interesting ungulates among insular native mammals that are part of the Plio-Pleistocene fossil fauna of the eastern islands of the Balearic Archipelago (Bover et al. 2008). Progressive dwarfism and changes in dentition gave rise to a species endemic to Gymnesians, the extinct *Myotragus balearicus* (Bate, 1909) (Bover et al. 2008; Palombo et al. 2013; Winkler et al. 2013). The first colonizing human populations are thought to have arrived on the islands about 4000 years before the present, which almost coincides with the last fossil records of *M. balearicus* (Bover et al. 2016). The most plausible scenario is based on a continuum between the last natural populations of native *M. balearicus* and the human introduction of new mammalian herbivores, mainly goats, rats, rabbits and sheep (Mayol et al. 2017).

6.3 Endemic Flora of the Canary and Balearic Islands and Their Vulnerability

The Canary Islands are located 96 km off the west coast of Africa, in the Macaronesian region, and the maximum altitude is located on Tenerife Island at 3718 m a.s.l. The archipelago harbours 2260 wild species of vascular plants, of which 597 are endemic, within 29 genera (Data Bank of Canary Islands Government). Hence, a high proportion of the flora on the Canary Islands is endemic (del Arco and Rodríguez-Delgado 2018). The archipelago is home to more than 50% of the endemic flora of Spain and exhibits the highest endemicity rate in Europe (Beltrán et al. 1999). Moreover, this archipelago has one of the highest percentages of endemic plants in the world (Whittaker and Fernández-Palacios 2007), including many unique ecosystems such as *Euphorbia* scrub and shrublands, thermo-sclerophyllous woodland, dry, humid and temperate laurel forests, Canary pine

forest, summit broom shrubland and a community of Teide violets. In terms of the vascular flora, circa 30% of all endemic species are estimated to be endangered (Caujapé-Castells et al. 2010) and this has the highest number of threatened plant species in Spain (del Valle et al. 2004).

The Balearic Archipelago, on the other hand, is located in the Western Mediterranean Basin. The maximum altitude is 1445 m a.s.l. (Mallorca). This Archipelago is home to 1551 plant species, of which 20 are endemic to the Thyrrenian Islands (including Corsica and Sardinia) and 140 are exclusive to the Balearic Archipelago (Rita and Payeras 2006; Sáez et al. 2013). The latest available version of the Balearic Islands flora red list considers 171 taxa under various categories of threat: high proportions of these threatened species are also endemic—56.5% in Mallorca, 17.7% in Menorca, 47.8% in Eivissa and 28.5% in Formentera (Sáez et al. 2017). The Archipelago encompasses many different habitats, including saltmarshes, temporary ponds, dunes, shrublands, forests and ravines. The disturbances caused by humans have changed over time; urbanization, construction of infrastructure and intensive agriculture in some areas and abandonment of agriculture in others, among other factors, are currently causing the loss or fragmentation of many habitats (Pons and Rullan 2014; Sáez et al. 2017).

Altogether, both archipelagos harbour a wide variety of endemic species and habitats of high conservation value due to endemism or rarity, all of which are currently being impacted to some degree by introduced mammalian herbivores. We will next describe how and when these herbivores arrived, their current population levels, and then analyse whether management strategies have been successful in mitigating these impacts and to what extent.

6.4 History of Exotic Mammalian Introductions and Current Status

Goats and sheep were probably introduced to the Canary Islands during the first millennium BC (Rando 2003; de Nascimento et al. 2020) while the European rabbit (*Oryctolagus cuniculus*) was introduced in the fifteenth century (de Abreu-Galindo 1977). Rabbits have the highest establishment success in the Archipelago (Nogales et al. 2006) and are present on all islands and habitats of the Archipelago, including the main islets—except for Montaña Clara, where they were successfully eradicated between 2000 and 2001 (Martín et al. 2002). Additional introduced mammals include the mouflon (*Ovis orientalis musimon*), which was introduced during 1970s to El Teide National Park (Tenerife), and Barbary sheep (*Ammotragus lervia*), introduced to Caldera de Taburiente National Park (La Palma) (Nogales et al. 2006). Both species have experienced substantial population increases over time, expanded to other ecosystems and been illegally trafficked to other islands from the same archipelago (La Gomera and Gran Canaria) (Rodríguez-Luengo, personal communication).

The introduction of exotic mammalian herbivores to the Balearic Islands coincides with the arrival of humans about 4000 years ago. Most of these animals

were intentionally introduced as cattle for food purposes, such as goats and sheep (Campbell and Donlan 2005). These species were managed and used by humans for centuries, and some populations were evolutionarily driven to form varieties of domestic animals such as the goat variety known as '*Cabra mallorquina*' from Mallorca or '*Cabra eivissenca*' from Eivissa. The first of these species is now used for hunting purposes, while the other is still used for cattle (Mayol et al. 2017).

During human colonization 4000 years ago, several species of small mammals such as rabbits and rats were also introduced, which rapidly dispersed and colonized all islands of the Archipelago (Traveset et al. 2009). Rats also colonized small islands in the Archipelago, such as Dragonera, Cabrera, es Vedrà and Conillera. Whereas rabbits are currently abundant in the centre and southern part of the Island of Mallorca and are widespread on the other islands, being particularly harmful on small islands such as Formentera and Cabrera and the islets (Santamaría et al. 2007; Capó et al. 2020; Rita et al. 2022). In addition, other more recently introduced herbivores are becoming free-ranging, including the European fallow deer [*Dama dama* (Linnaeus, 1758)], which will probably expand across these islands in the near future (Pinya and Lassnig 2018).

More recently, significant land-use change occurred in the Balearic Islands during the 1960s with the shift from agriculture to tourism (Pons and Rullan 2014), which led to the abandonment of many populations of ungulates (mainly goats). As a result, feral populations of goats were established on the mountains and natural areas of Mallorca (Vives and Baraza 2010). Their high reproductive rate and lack of management allowed the populations to grow rapidly and led to overpopulation within a few decades (Mayol et al. 2017; Limpens et al. 2020). At present, the overpopulation of goats is considered one of the major threats to plant communities on these islands (Moragues et al. 2015; Mayol et al. 2017; Capó et al. 2021, 2022).

6.5 Impacts of Introduced Mammalian Herbivores on Both Insular Systems

The introduction of the first mammalian herbivores to the Canary and Balearic Islands is dated before the start of ecosystem studies, which makes it difficult to compare data of herbivory impacts before and after introductions. In addition, there is no information on the historical distribution of plant species that are currently constrained to areas inaccessible to herbivores (i.e., cliffs or mountain walls) and on potential plant species extinctions during the last few centuries. Hence, the richness and composition of the original plant communities could differ remarkably from the current vegetation—many insular endemic species could have disappeared or drastically reduced their populations due to the introduction of mammalian herbivores, as reported for other islands worldwide (Wood et al. 2017). Therefore, it is difficult to evaluate the ecological degradation due to introduced mammalian herbivores in most ecosystems, complicating the design of suitable vegetation restoration strategies. As an example, *Thesium psilotocladum* Svent was last seen on Tenerife in 1983. Since then, repeated searches in its classic localities have been unsuccessful.

Uncontrolled livestock has been pointed out as the main cause of the extinction of this species (Martín-Cáceres et al. 2004).

6.5.1 Impact of Herbivory by Feral Goats

Goats are considered one of the most pernicious invasive species on islands around the world (Lowe et al. 2004). Herbivory by goats can drive dramatic decreases in the population size of endemic plant species, with the remaining restricted to areas where herbivores find it difficult to access (Nogales et al. 1992; Pisanu et al. 2012) or eventually become extinct (Roemer et al. 2002; Genovesi and Shine 2004; Campbell and Donlan 2005; Garzón-Machado et al. 2010). They can also severely defoliate shrub species, causing severe damage on the plant (Chynoweth et al. 2013; Limpens et al. 2020; Capó et al. 2021) (Fig. 6.1). They can also indirectly affect endemic fauna such as insular lizards by altering their habitat and competing for resources (Nogales et al. 1992), invertebrate communities (Jauregui et al. 2008), as well as mutualistic interactions such as seed dispersion or pollination (Traveset and Richardson 2006; Capó et al. 2022).

In the Canary Islands, the presence of goats has contributed to the degradation of natural ecosystems and plant communities (Gangoso et al. 2006; Fernández-Lugo et al. 2013). This trend has continued since their introduction, mainly due to the economic benefits of the species for the aboriginal inhabitants and Europeans (Rando 2014). In fact, goats are feral on all of the Canary Islands, especially in specific areas defined as Natural Protected Areas. However, feral goats eradication programmes have been difficult to implement or continue for social reasons (Fernández-Lugo et al. 2013).

In the Balearic Islands, feral goats foraging areas are very stable during the year between 45 and 170 ha (Ibáñez et al. 2019). However, there is strong temporal variation in their diet depending on the season of the year and the type of vegetation they feed (Rivera-Sánchez 2014). Although it is not uncommon to see feral goat populations throughout the mountainous areas of Mallorca, these animals show a

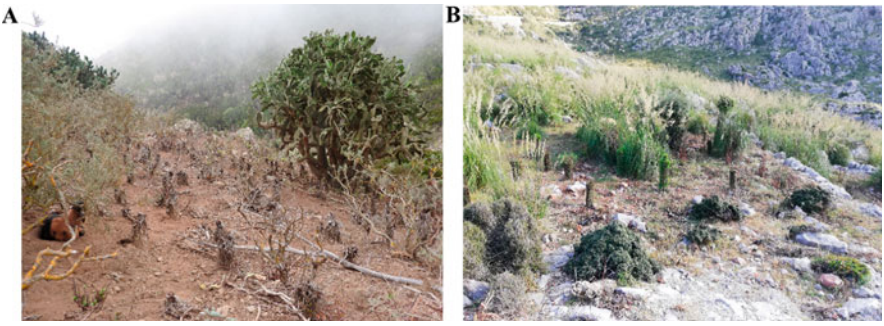

Fig. 6.1 Examples of plant communities on the Canary Islands (**a**) and Balearic Islands (**b**) that are severely affected by overpopulation of goats

preference for the highest and rockiest areas (Limpens et al. 2020). At the same time, these habitats are also hotspots of endemic flora, such as the mountain peaks of the northern mountain range (Moragues et al. 2015). Still, literature on the effects of goats on the Balearic Islands vegetation is scarce; only a few studies have reported severe threats to endemic species (Cursach and Rita 2012; Capó 2021) and vegetation at the population level, such as the case of *Euphorbia dendroides* L. (Capó et al. 2021), and at the community level, as observed in Es Vedrà islet (Capó et al. 2022). The impact of goats can also occur through indirect effects, such as the habitat disappearance due to soil erosion in the case of *Naufraga balearica* Constance & Cannon. Even though goats can favour *N. balearica* plant survival by predation of its competitor species, they also impact the species by increasing soil nitrification and erosion (Cursach et al. 2013).

6.5.2 Effects of the European Rabbit

Rabbits directly affect a large number of endemic and native plant species found on islands (Chapuis et al. 1995). These herbivores mainly predate seedlings and young individuals, making an assessment of their impact hard to detect in the short term (Cubas et al. 2018; Capó et al. 2021). These effects, however, are expressed over longer-term periods even after eradication and are intensified by impoverishment of the seed bank in the soil (Edwards and Crawley 1999; Bueno et al. 2011; González-Mancebo et al. 2019), especially due to the significant impact of rabbits on the juvenile stages of plants (Gómez-Aparicio et al. 2005; Irl et al. 2012; Cubas et al. 2017, 2018; Capó et al. 2021) and their influence on seed recruitment (Nogales et al. 1995, 2005; Martín et al. 2003).

In the Canary Islands, information on their ecological impacts in the archipelago was surprisingly scarce until recently (Garzón-Machado et al. 2010; Irl et al. 2012; Cubas et al. 2018, 2019, 2021; González-Mancebo et al. 2019) and their negative effects are considered a direct threat to many endangered and keystone insular species (Bañares et al. 2004, 2008, 2010; Carqué et al. 2004; Moreno 2008; Seguí et al. 2017). For instance, several key accompanying species of *Pinus canariensis* C. Sm. ec DC. in the Canarian pine forest (Bello-Rodríguez et al. 2019; Cubas et al. 2022) are now restricted to rupicolous areas due to the disappearance of all accessible populations to rabbits (Garzón-Machado et al. 2010).

The impacts of rabbits on insular endemic species have also been reported for the Balearic Islands, mainly in terms of fruit and seed predation or herbivory of vegetative structures (Santamaría et al. 2007; Capó et al. 2020). Specifically, the impact of rabbits on the endangered *Medicago citrina* (Font Quer) Greuter has been exhaustively investigated on the small islands of the Balearic Archipelago. Some studies have shown that this species is absent from the large island of Cabrera because both rats and rabbits consume seeds and seedlings arriving from surrounding islets (Latorre et al. 2013). Interestingly, and among the few successful cases, another study reported that new seeds of *M. citrina* germinated and a population of more than

2000 individuals established within a few years after eradication of rabbits on an islet close to Eivissa island (Rita et al. 2022).

6.6 Case Studies of Highly Threatened Endemic Species

On both archipelagos, there are many cases in which the impact of introduced mammalian herbivores comprises their conservation status (Moreno 2008; Bañares et al. 2010; Sáez et al. 2017). From this large number of species, we have selected three threatened endemic species whose most important threatening factor is introduced mammalian herbivores requiring urgent management strategies (i.e., fencing, herbivore population control) in order to guarantee their conservation.

6.6.1 *Cytisus supranubius* (Tenerife and La Palma, Canary Islands)

Cytisus supranubius (L.f.) Kuntze is considered a keystone species characteristic of alpine ecosystems in the Canary Islands (particularly on Tenerife), which should be considered vulnerable according to the general criteria established by the IUCN (Cubas et al. 2022). This species was considered to be in decline in the 1940s (Sventenius 1946), but the establishment of El Teide National Park in 1954 prohibited the human use of this species (previously used as pasture, for firewood and bedding for livestock). In addition, goats were eradicated within the limits of the National Park, which led to a dramatic reduction in herbivore pressure (Rodríguez-Delgado and Elena-Rosselló 2006). These important conservation measures led to a strong increase in the population of *C. supranubius* in subsequent years with a notable expansion in later decades, as demonstrated by the distribution maps of this species (del Arco and Rodríguez-Delgado 2018) and aerial photographs (Kyncl et al. 2006).

In the last 32 years, *C. supranubius* has experienced a 28.7% decline in its distribution (Cubas et al. 2022). This reduction is negatively correlated with temperature and positively correlated with precipitation. Climate change, especially prolonged droughts, is contributing to an increase in the mortality rate of this species (Olano et al. 2017). However, the most important factor that explains the decline of this species is the impact of European rabbit (Cubas et al. 2018). In a recent study including rabbit and mouflon exclusion plots across 13 sites of summit vegetation, Cubas et al. (2018) found that the European rabbit was the main cause for the decline in the Teide broom population. Outside the fences, the number of juveniles is almost non-existent (<2%) (Cubas et al. 2018). This suggests that exclusion of mouflon alone will not lead to recovery of the population structure of this species (Cubas et al. 2018). The present-day Teide broom shrublands without recruitment exhibit ageing of the shrubs and a high number of dead individuals (Cubas et al. 2018).

The impact of the European rabbit on the Teide shrubland can also operate through different pathways, in many cases involving complex mechanisms. For instance, one relates to an increase in the representation of clones within

C. supranubius populations. Rabbit seed herbivory increases the representation of clonally produced offspring, leading to reduced cross-fertilization by natural pollinators of this species, ultimately causing reduced seed viability due to inbreeding (Pérez de Paz et al. 2017). In many areas, these clones form large groups of shrubs with low vitality and lower reproductive output (Cubas 2020), thus reinforcing the direct negative effects of the European rabbit on vegetation regeneration in the Teide broom.

By impacting this species, rabbits also have indirect effects on the ecosystem. This can occur because *C. supranubius* is a major nitrogen fixer in the ecosystem (Wheeler and Dickson 1990; Pulido-Suárez et al. 2021), and reductions in its abundance consequently lead to a reduction in total soil nitrogen, and thus negative impacts on other plant species (Cubas et al. 2022). The presence of rabbit latrines has been also shown to alter the soil rhizobial populations within the ecosystem and can favour co-entrance of non-nodulating bacteria into the root nodules of plants, which can affect N-fixing symbiosis (Pulido-Suárez et al. 2021).

6.6.2 *Coristospermum huteri* and *Agrostis barceloi* (Mallorca, Balearic Islands)

Coristospermum huteri (Porta) L.Sáez & Rosselló and *Agrostis barceloi* (Porta) L. Sáez & Rosselló are endemic species to the Balearic Islands catalogued as Critically Endangered on both the Red List of Vascular Flora of Spain (Moreno 2008) and the Red List of Vascular Flora of the Balearic Islands (Sáez et al. 2017). These species are also classified at the highest threat level according to the Decree 75/2005 (Balearic Catalogue of Endangered Species, Special Biological Protection Areas) (BOIB 2005). These plants only occur at the summit of the highest mountain on Mallorca Island, Puig Major, at 1200–1400 m a.s.l. The summit of this mountain represents a hotspot of extremely narrow endemic species and other endangered plant species, as this unique site on the Balearic Islands has sufficient elevation to function as a suitable refuge in the present interglacial period (López-Pujol et al. 2013). However, herbivory pressure, mainly by feral goats, poses a major threat to the conservation of this site.

Coristospermum huteri is a perennial herb that inhabits limestone cliffs in shaded and slightly moist rocky areas; its entire population consists of ca. 400 individuals (of which more than 200 are transplanted individuals) distributed within an area smaller than 0.1 km^2 (Bibiloni et al. 2017). Its biology has not yet been fully studied, though this species has been reported to have extremely low genetic diversity (allozyme markers) (López-Pujol et al. 2013); this is a common rule for species with small population sizes, especially in island populations. Generally, the number of reproductive individuals is very low: only 9 individuals bloomed in 2006 (Forteza 2007), 3 in 2007, 2 in 2008, 12 in 2009, 5 in 2010, 13 in 2011 (López-Pujol et al. 2013), 12 in 2015 (Bibiloni et al. 2017) and 17 in 2022 (L. Sáez, personal communication). Anthropogenic threats have also affected the population of *C. huteri* over recent decades. Historical records indicate that the species was very abundant in the

summit area (Bonafè 1979); however, plants could have been destroyed by construction of a radar facility for military purposes in 1958 (Sáez and Roselló 2004; Moragues et al. 2015). At present, the major threats are drought and herbivory by introduced mammalian herbivores, with the latter causing a reduction of up to 50% in the population during the late twentieth century (Mayol and Bibiloni 2005). Due to the poor conservation status of the species, recovery plans have been designed and implemented (BOIB 2008); several measures have been implemented in the last decades to avoid a decrease in the population sizes, mainly by controlling the impact of goat herbivory by fencing. To complement these efforts, control of competitor plant species inside the fenced area has also been implemented and plants were transplanted to increase the population. Globally, these management measures have improved the population size, but conservation actions must continue to reduce the impact of feral goats. A significant decrease in the feral goat populations would highly benefit the conservation of this species. In addition, other factors threaten the survival of the species, such as the low habitat availability and its very low reproductive performance.

Agrostis barceloi is a short rhizomatous perennial grass up to 30 cm in height that occurs in three subpopulations of an area of 170 m^2 (Sáez and Rosselló 2004; Massó et al. 2016). The rupicolous plant grows on shadow rock crevices and moist soils at the base of cliffs—generally north-facing—and is a tetraploid ($2n = 28$) species (Sáez and Rosselló 2000). Generally, the number of reproductive individuals is very low; the population size fluctuates widely over the years and the species undergoes clonal reproduction (Sáez and Rosselló 2004; Moragues et al. 2015). Previous studies reported no genotypic variability in this species, which can be attributed to a founder effect, the very small effective population size and a series of threats affecting the population (Massó et al. 2016). Predation of leaves and inflorescences certainly constitutes the major threat to the species; thus, conservation strategies including fencing and removal of competitor plants have been performed in recent years according to the Recovery Plan for this species (BOIB 2008). Indeed, fencing was initially very effective, as the number of inflorescences increased from 36 in 2007 to 1255 in 2008 (Moragues et al. 2015). Moreover, the habitat disturbance due to construction of the previously mentioned military installations in the 1950s and episodes of drought affect the persistence of the species (Sáez and Rosselló 2004; Massó et al. 2016). Overall, similarly to the case of *C. huteri* described above, ongoing management measures related to controlling the herbivory pressure are critical for the conservation of *A. barceloi*; demographic monitoring, improved knowledge of the biology of the species and creation of *ex-situ* collections are also essential for long-term conservation.

6.7 Multidisciplinary Perspectives and Recommendations

Management of introduced herbivores affects a variety of social stakeholders with contrasting points of view, which can lead to confrontational dynamics that inhibit policymakers from implementing interventions. Thus, it is crucial to include many

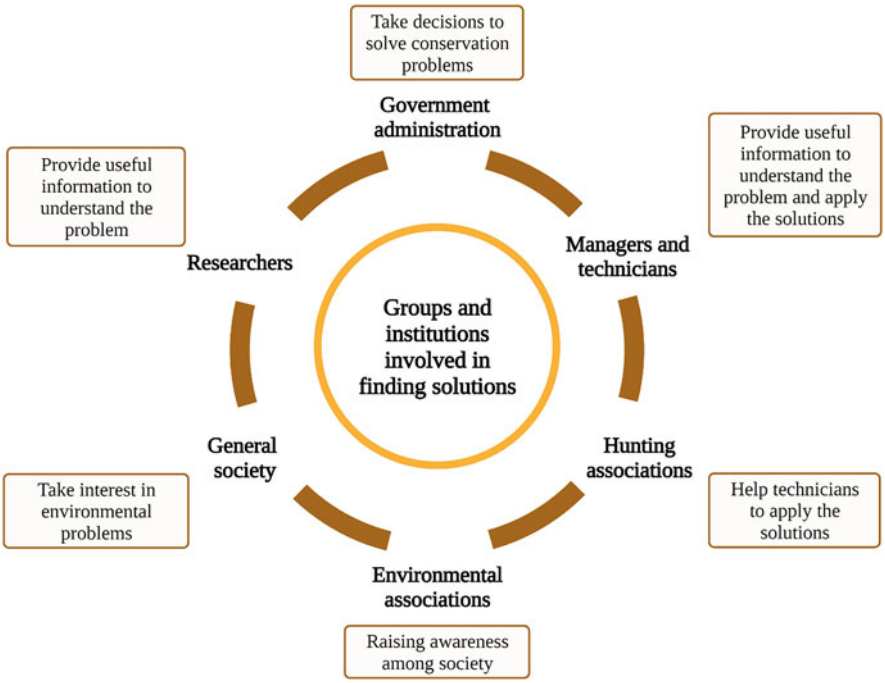

Fig. 6.2 Multidisciplinary scheme illustrating the major stakeholders implicated in the management of introduced mammalian herbivores and the roles they should play in application of suitable solutions

agents from society in order to properly manage multidisciplinary problems as the one presented in this chapter. In this section, we present the major social issues that must be considered in order to effectively manage and palliate the impact of introduced mammalian herbivores on both the Canary Islands and Balearic Islands (Fig. 6.2).

6.7.1 Government Administration

Conservation actions and decisions taken by environmental authorities can eventually be refused by society due to controversial social perception of mammalian herbivores on both archipelagos. For instance, in 2016, the Government of the Balearic Islands decided to eradicate the feral goats from a small islet located close to the island of Eivissa for conservation purposes. This decision translated into extraordinary recovery of the vegetation, especially of endemic plant species (Capó et al. 2022). However, at the same time, this decision was not well received by animalism parties and some citizens, and required judicial intervention (Rita 2016). This case illustrates how these policy actions are essential to consider a multidisciplinary point of view in order to guarantee their effectiveness in the long term.

6.7.2 Managers and Technicians

Environmental managers and conservationist technicians play an essential role in the creation of suitable strategies and programmes to address the impact of introduced mammalian herbivores. In some cases, complete eradication is difficult or even impossible; therefore, population control of the herbivores must be continuously performed to maintain the population density at low levels. This option is often difficult for several reasons, depends on the use of the area and an appropriate strategy needs to be designed (i.e., exclusion fences, hunting area, experimental areas, public-use areas, etc.) (Capó et al. 2021).

6.7.3 Researchers

Ongoing scientific studies must be carried out to generate new information that can help both government leaders and managers to design and implement efficient strategies. This information must also contribute to raising awareness to society through outreach activities and dissemination of results in non-scientific programmes, journals and media. Even though recent information has been generated to indicate which species and areas are more affected by introduced mammalian herbivores on both archipelagos (Cubas et al. 2018, 2019; Muñoz-Gallego et al. 2019, 2022; Limpens et al. 2020; Bello-Rodríguez et al. 2021; Capó et al. 2021, 2022; Ibañez-Álvarez et al. 2022; Rita et al. 2022), managers still demand more answers in order to design control and eradication programmes. Further studies must focus on disentangling the influence of introduced herbivores on the demographic structures, recruitment, germination and ecological interactions of threatened endemic species.

6.7.4 Hunting Associations

It is not rare that hunter authorities and associations take responsibility and collaborate with environmental management authorities with the purpose to control ungulate populations in order to prevent ecosystem and animal population degradation. However, common hunting techniques used to eradicate ungulates from islands (Campbell et al. 2004; Campbell and Donlan 2005) usually require hunters to be specially trained to optimize their fieldwork (Carrion et al. 2011). Hence, the collaboration of hunters with management programmes is desirable, under appropriate supervision by environmental authorities, to guarantee an optimal conservation strategy.

6.7.5 General Society and Environmental Associations

General society plays a key role in visualizing the importance of environmental problems and finding optimal solutions. In particular, environmental problems need to be communicated to urban areas, where it is very difficult to have a realistic perception of the problem and possible solutions. In this sense, it is very important that society knows and understands the importance of conserving valuable natural places, the serious problem of introduced herbivores and the limited management options that can be realistically applied (i.e., eradication of goats from islets or other crucial spots). Also, environmental associations can play a very important role in raising awareness among society about the problems of introduced herbivores on conservation of the natural heritage.

6.7.6 Animalism Versus Conservationism

The most defeating conflict that conservation managers face in terms of environmental policies is the confrontation between animalism and ecologism (López-i-Gelats et al. 2021). Animalism prioritizes the well-being of animals, frequently with a bias towards species that are phylogenetically close to humans or that have domestic traditions (Bailey 2015). In contrast, ecologism considers the ecosystem to be important as a whole (Baxter 1999). Hence, animalism and ecologism have opposing views on the role of introduced mammalian herbivores: animalism considers introduced herbivores as new members of the ecosystem that nature should adapt to, and considers killing the mammals as a crime. On the other hand, ecologists consider the introduced herbivores as a threat to the conservation of nature and that their elimination (with maximum effort to avoid unnecessary suffering) is necessary to guarantee the survival of native species of flora and fauna.

6.8 Conclusions and Final Remarks

This chapter reviews the current studies about the impact of non-native mammalian herbivores, notably goats and rabbits, on the ecosystems of the Canary and Balearic Archipelagos. The Canary Islands, due to their oceanic origins and lack of native mammalian history, appear to be more susceptible to these invasive species. In contrast, the Balearic Islands once housed native mammals like the bovid *Myotragus balearicus*, which potentially exerted evolutionary pressures on certain species but others seem to be vulnerable to herbivory. Anyway, the current proliferation of non-native mammal herbivores in both archipelagos poses significant threats to native plant communities due to overgrazing, with endemic species being especially vulnerable. To address these ecological challenges, comprehensive strategies are imperative. These should involve collaboration among a wide spectrum of stakeholders, ensuring a cohesive approach that factors in varied perspectives to counteract the adverse impacts of these invasive species effectively.

References

Bailey AM (2015) Animalism. Philos Compass 10:867–883. https://doi.org/10.1111/phc3.12263
Bañares A, Blanca G, Güemes J et al (2004) Atlas y libro rojo de la flora vascular amenazada de España. Dirección General de Conservación de la Naturaleza, Madrid
Bañares A, Blanca G, Güemes J et al (2010) Atlas y libro rojo de la flora vascular amenazada de España. Adenda 2010. Ministerio de Medio Ambiente, Medio Rural y Marino - Sociedad Española de Biología de la Conservación de Plantas, Madrid
Bañares A, Blanca G, Güemes J et al (2008) Atlas y libro rojo de la flora vascular amenazada de España. Adenda 2008. Dirección General de Conservación de la Naturaleza, Madrid
Barahona F, Rage JC, García-Talavera F (1998) The first record of snakes on the Canary Islands: a vertebra from the Upper Miocene of Lanzarote. Amphib Reptil 19:419–425. https://doi.org/10.1163/156853898X00070
Baxter B (1999) Ecologism. Edinburgh University Press, Edinburgh
Bello-Rodríguez V, Cubas J, Del Arco MJ et al (2019) Elevational and structural shifts in the treeline of an oceanic island (Tenerife, Canary Islands) in the context of global warming. Int J Appl Earth Obs Geoinf 82:101918. https://doi.org/10.1016/j.jag.2019.101918
Bello-Rodríguez V, Mateo RG, Pellissier L et al (2021) Forecast increase in invasive rabbit spread into ecosystems of an oceanic island (Tenerife) under climate change. Ecol Appl 31:e02206. https://doi.org/10.1002/eap.2206
Beltrán E, Wildpret de la Torre W, Leon Arencibia MC et al (1999) Libro rojo de la flora canaria contenida en la Directiva Hábitats europea. Ministerio de Medio Ambiente, Medio Rural y Marino, San Cristóbal de la Laguna
Bibiloni G, Fraga P, Moragues E et al (2017) Ligusticum huteri. In: Pasta S, Pérez-Graber A, Fazan L, Montmollin B (eds) The Top 50 Mediterranean Island Plants UPDATE 20172. IUCN/SSC/Mediterranean Plant Specialist Group, Neuchâtel, Switzerland
Bird P, Mutze G, Peacock D, Jennings S (2012) Damage caused by low-density exotic herbivore populations: the impact of introduced European rabbits on marsupial herbivores and Allocasuarina and Bursaria seedling survival in Australian coastal shrubland. Biol Invasions 14:743–755. https://doi.org/10.1007/s10530-011-0114-8
BOIB (2005) Decret 75/2005, de 8 de juliol, pel qual es crea el Catàleg Balear d'Espècies Amenaçades i d'Especial Protecció, les Àrees Biològiques Crítiques i el Consell Assessor de Fauna i Flora de les Illes Balears. Spain
BOIB (2008) Resolució del conseller de Medi Ambient de 26 de novembre de 2008 per la qual s'aproven els plans de recuperació de Vicia bifoliolata, d'aus aquàtiques catalogades en Perill d'Extinció de les Illes Balears (Pla Homeyer); el pla de conservació de la flora. Spain
Bonafè F (1979) Flora de Mallorca. Editorial Moll, Palma
Bover P, Quintana J, Alcover JA (2010) A new species of Myotragus Bate, 1909 (Artiodactyla, Caprinae) from the Early Pliocene of Mallorca (Balearic Islands, western Mediterranean). Geol Mag 147:871–885. https://doi.org/10.1017/S0016756810000336
Bover P, Quintana J, Alcover JA (2008) Three islands, three worlds: paleogeography and evolution of the vertebrate fauna from the Balearic Islands. Quat Int 182:135–144. https://doi.org/10.1016/j.quaint.2007.06.039
Bover P, Valenzuela A, Torres E et al (2016) Closing the gap: new data on the last documented Myotragus and the first human evidence on Mallorca (Balearic Islands, Western Mediterranean Sea). Holocene 26:1887–1891. https://doi.org/10.1177/0959683616645945
Bried J, Magalhães MC, Bolton M et al (2009) Seabird Habitat restoration on praia islet, Azores Archipelago. Ecol Restor 27:27–36. https://doi.org/10.3368/er.27.1.27
Bueno CG, Reiné R, Alados CL, Gómez-García D (2011) Effects of large wild boar disturbances on alpine soil seed banks. Basic Appl Ecol 12:125–133. https://doi.org/10.1016/j.baae.2010.12.006
Campbell K, Donlan CJ (2005) Feral goat eradications on islands. Conserv Biol 19:1362–1374. https://doi.org/10.1111/j.1523-1739.2005.00228.x

Campbell K, Donlan CJ, Cruz F, Carrion V (2004) Eradication of feral goats Capra hircus from Pinta Island, Galápagos, Ecuador. Oryx 38:328–333. https://doi.org/10.1038/nrg1358

Capizzi D (2020) A review of mammal eradications on Mediterranean islands. Mamm Rev 50:124–135. https://doi.org/10.1111/mam.12190

Capó M (2021) Preadaptación y vulnerabilidad de la vegetación de las Islas Baleares frente a la herbivoría de vertebrados no nativos. Universitat de les Illes Balears

Capó M, Cursach J, Picorelli V et al (2022) Eradication of feral goats, not population control, as a strategy to conserve plant communities on Mediterranean islets. J Nat Conserv 65:126108. https://doi.org/10.1016/j.jnc.2021.126108

Capó M, Cursach J, Rita J (2020) Disentangling the pollination system of the food-deceptive orchid Anacamptis longicornu (Orchidaceae): from breeding system to spatio-temporal variation in reproductive success. Plant Biosyst 154:306–315. https://doi.org/10.1080/11263504.2019.1610110

Capó M, Engelbrecht C, Cardona C et al (2021) Mildly toxic shrubs as indicators of goats herbivory gives information for the management of natural landscapes on Mediterranean islands. Sci Total Environ 786:147391. https://doi.org/10.1016/j.scitotenv.2021.147391

Carqué E, Durbán M, Marrero-Gómez M, Bañares-Baudet Á (2004) Influencia de los herbívoros introducidos en la supervivencia de Stemmacantha cynaroides (Asteraceae). Una especie amenazada de las islas Canarias. Vieraea 32:97–105

Carrion V, Donlan CJ, Campbell KJ et al (2011) Archipelago-wide island restoration in the galápagos islands: reducing costs of invasive mammal eradication programs and reinvasion risk. PLoS One 6:e18835. https://doi.org/10.1371/journal.pone.0018835

Castillo C, Rando JC, Zamora JF (1994) Discovery of mummified extinct giant lizards (Gallotia goliath, Lacertidae) in Tenerife, Canary Islands. Bönner Zool Beiträge 45:129–136

Caujapé-Castells J, Tye A, Crawford DJ et al (2010) Conservation of oceanic island floras: present and future global challenges. Perspect Plant Ecol Evol Syst 12:107–129. https://doi.org/10.1016/j.ppees.2009.10.001

Ceballos L, Ortuño F (1951) Estudio sobre la vegetación y la flora forestal de las Canarias Occidentales. Ministerio de Agricultura. Dirección General de Montes, Caza y Pesca Flucial. Instituto Forestal de Investigaciones y Experiencias, Madrid

Chapuis J, Barnaud G, Bioret F et al (1995) L'éradication des espèces introduites, un préalable à la restauration des milieux insulaires. Cas des iles françaises. Natures-Sciences-Sociétés 3:53–67

Chapuis JL, Frenot Y, Lebouvier M (2004) Recovery of native plant communities after eradication of rabbits from the subantarctic Kerguelen Islands, and influence of climate change. Biol Conserv 117:167–179. https://doi.org/10.1016/S0006-3207(03)00290-8

Chynoweth MW, Litton CM, Lepczyk CA et al (2013) Biology and impacts of pacific island invasive species. 9. Capra hircus, the feral goat (mammalia: Bovidae). Pac Sci 67:141–156. https://doi.org/10.2984/67.2.1

Cooke BD (2012) Rabbits: manageable environmental pests or participants in new Australian ecosystems? Wildl Res 39:279–289

Courchamp F, Chapuis JL, Pascal M (2003) Mammal invaders on islands: impact, control and control impact. Biol Rev Camb Philos Soc 78:347–383

Croft DA, Heaney LR, Flynn JJ, Bautista AP (2006) Fossil remains of a new, diminutive Bubalus (Artiodactyla: Bovidae: Bovini) from Cebu Island, Philippines. J Mammal 87:1037–1051. https://doi.org/10.1644/06-MAMM-A-018R.1

Crusafont-Pairo M, Petter F (1964) Un Murine Geant Fossile Des Iles Canaries Canariomys Bravoi Gen. Nov., Sp. Nov. (Rongeurs, Muridés). Mammalia 28:607–612. https://doi.org/10.1515/mamm.1964.28.4.607

Cubas J (2020) El impacto del conejo europeo como ingeniero de ecosistemas en Canarias. PhD thesis, Universidad de la Laguna

Cubas J, Irl SDH, Villafuerte R et al (2019) Endemic plant species are more palatable to introduced herbivores than non-endemics. Proc R Soc B Biol Sci 286:20190136. https://doi.org/10.1098/rspb.2019.0136

Cubas J, Kluge J, Bello-Rodríguez V et al (2021) Can habitat type predict the abundance of the European rabbits on oceanic islands? Community Ecol 22:93–105. https://doi.org/10.1007/s42974-021-00039-6

Cubas J, Martín-Esquivel JL, del Arco M, González-Mancebo JM (2017) El conejo europeo como ingeniero del paisaje en la alta montaña canaria. Conserv Veg 21:14–17

Cubas J, Martín-Esquivel JL, Marrero-Gómez M et al (2022) Climate change causes rapid collapse of a keystone shrub from insular Alpine ecosystems. J Nat Conserv 69:126263. https://doi.org/10.1016/j.jnc.2022.126263

Cubas J, Martín-Esquivel JL, Nogales M et al (2018) Contrasting effects of invasive rabbits on endemic plants driving vegetation change in a subtropical alpine insular environment. Biol Invasions 20:793–807. https://doi.org/10.1007/s10530-017-1576-0

Cursach J, Moragues E, Rita J (2013) Herbivory and plant competition effects on the population dynamics of Naufraga balearica, a threatened narrow endemic species of the Balearic Islands. Plant Biosyst 147:508–517. https://doi.org/10.1080/11263504.2012.745456

Cursach J, Rita J (2012) Reproductive biology of Ranunculus weyleri (Ranunculaceae), a narrowly endemic plant from the Balearic Islands with disjunct populations. Flora Morphol Distrib Funct Ecol Plants 207:726–735. https://doi.org/10.1016/j.flora.2012.07.004

del Arco M, Rodríguez-Delgado O (2018) Vegetation of the Canary Islands. In: Vegetation of the Canary Islands: plant and vegetation. Springer, pp 83–319

de Nascimento L, Nogué S,Naranjo-Cigala A, et al (2020) Human impact and ecological changes during prehistoric settlement on the Canary Islands. Quaternary Sci Rev 239:106332. https://doi.org/10.1016/j.quascirev.2020.106332

del Valle E, Maldonado J, Sainz H, Sánchez de Dios R (2004) Áreas importantes para la flora amenazada española. In: Bañares A, Blanca G, Güemes J et al (eds) Atlas y Libro rojo de la flora vascular amenazada de España. Dirección General de Conservación de la Naturaleza, Madrid, pp 979–1007

Donlan CJ, Tershy BR, Croll DA (2002) Islands and introduced herbivores: conservation action as ecosystem experimentation. J Appl Ecol 39:235–246. https://doi.org/10.1046/J.1365-2664.2002.00710.X

Edwards GR, Crawley MJ (1999) Herbivores, seed banks and seedling recruitment in mesic grassland. J Ecol 87:423–435. https://doi.org/10.1046/j.1365-2745.1999.00363.x

Fernández-Lugo S, Arévalo JR, de Nascimento L et al (2013) Long-term vegetation responses to different goat grazing regimes in semi-natural ecosystems: a case study in Tenerife (Canary Islands). Appl Veg Sci 16:74–83. https://doi.org/10.1111/j.1654-109X.2012.01211.x

Fernández-Palacios JM (2004) Introducción a las islas. In: Fernández-Palacios JM, Morici C (eds) Island ecology. Asociación Española de Ecología Terrestre, Cabildo Insular de la Palma, pp 21–55

Forteza V (2007) Ligusticum huteri. In: Bioatles, 2nd edn. Conselleria de Medi Ambient, Agricultura i Pesca, Palma

Galindo JA (1977) Historia de la conquista de las siete islas de Canarias. Ediciones Goya, Santa Cruz de Tenerife

Gangoso L, Donázar JA, Scholz S et al (2006) Contradiction in conservation of island ecosystems: plants, introduced herbivores and avian scavengers in the Canary Islands. Biodivers Conserv 15:2231–2248. https://doi.org/10.1007/s10531-004-7181-4

Garzón-Machado V, González-Mancebo JM, Palomares-Martínez A et al (2010) Strong negative effect of alien herbivores on endemic legumes of the Canary pine forest. Biol Conserv 143:2685–2694. https://doi.org/10.1016/j.biocon.2010.07.012

Genovesi P, Shine C (2004) European strategy on invasive alien species. Nat Environ 137:1–68

Gómez-Aparicio L, Zamora R, Gómez JM (2005) The regeneration status of the endangered Acer opalus subsp. granatense throughout its geographical distribution in the Iberian Peninsula. Biol Conserv 121:195–206. https://doi.org/10.1016/j.biocon.2004.04.019

González-Mancebo JM, Cubas J, Bello-Rodríguez V, del Arco M (2019) Cinco siglos de invasión del conejo europeo (Oryctolagus cuniculus L.) en ecosistemas árido-secos de Tenerife. Vieraea 46:597–624

Hutterer R, Lopez-martinez N, Michaux J (1988) A new rodent from quaternary deposits of the Canary Islands and its relationships with neogene and recent murids of Europe and Africa. Palaeoverlebrala 18:241–262

Ibañez-Álvarez M, Santasusana PF, Calleja JA et al (2022) Satellite-based monitoring of primary production in a mediterranean islet post black rat eradication. Remote Sens 14:1–18. https://doi.org/10.3390/rs14010101

Ibáñez M, Gort A, Baraza E, et al (2019) Pattern of territory use by feral goats on insular mediterranean habitats. In: Proceedings of the II Movement Ecology Brazil Meeting. Campo Grande, Brasil

Irl SDH, Steinbauer MJ, Babel W et al (2012) An 11-yr exclosure experiment in a high-elevation island ecosystem: introduced herbivore impact on shrub species richness, seedling recruitment and population dynamics. J Veg Sci 23:1114–1125. https://doi.org/10.1111/j.1654-1103.2012.01425.x

Jauregui BM, Rosa-Garcia R, Garcia U et al (2008) Effects of stocking density and breed of goats on vegetation and grasshopper occurrence in heathlands. Agric Ecosyst Environ 123:219–224. https://doi.org/10.1016/j.agee.2007.06.004

Kreft H, Jetz W, Mutke J et al (2008) Global diversity of island floras from a macroecological perspective. Ecol Lett 11:116–127. https://doi.org/10.1111/j.1461-0248.2007.01129.x

Krijgsman W, Hilgen FJ, Raffi I et al (1999) Chronology, causes and progression of the Messinian salinity crisis. Nature 400:652–655. https://doi.org/10.1038/23231

Kyncl T, Suda J, Wild J et al (2006) Population dynamics and clonal growth of Spartocytisus supranubius (Fabaceae), a dominant shrub in the alpine zone of Tenerife, Canary Islands. Plant Ecol 186:97–108. https://doi.org/10.1007/s11258-006-9115-6

Lange RT, Graham CR (1983) Rabbits and the failure of regeneration in Australian arid zone Acacia. Aust J Ecol 8:377–381. https://doi.org/10.1111/j.1442-9993.1983.tb01334.x

Latorre L, Larrinaga AR, Santamaría L (2013) Combined impact of multiple exotic herbivores on different life stages of an endangered plant endemism, Medicago citrina. J Ecol 101:107–117. https://doi.org/10.1111/1365-2745.12005

Lenzner B, Latombe G, Capinha C et al (2020) What will the future bring for biological invasions on islands? An expert-based assessment. Front Ecol Evol 8:1–16. https://doi.org/10.3389/fevo.2020.00280

Limpens A, Serrano E, Rivera-Sánchez L et al (2020) Pellet accumulation as a proxy for herbivore pressure in a mediterranean ecosystem. Rangel Ecol Manag 73:636–641. https://doi.org/10.1016/j.rama.2020.06.011

López-i-Gelats F, Alomar D, Baraza E, Bartolomé J (2021) Discourses on rewilding: the case of feral goats in Mallorca. Hum Ecol 49:225–232. https://doi.org/10.1007/s10745-021-00226-z

López-Jurado LF, Mateo JA (1993) A new giant land tortoise from the Pliocene of Gran Canaria (Canary Island). Rev Espaola Herpetol 7:107–111

López-Pujol J, Martinell MC, Massó S et al (2013) The "paradigm of extremes": extremely low genetic diversity in an extremely narrow endemic species, Coristospermum huteri (Umbelliferae). Plant Syst Evol 299:439–446. https://doi.org/10.1007/s00606-012-0732-3

Lowe S, Browne M, Boudjelas S, de Poorter M (2004) 100 de las Especies Exóticas Invasoras más dañinas del mundo. Una selección del Global Invasive Species Database

Martín-Cáceres K, Santos-Guerra A, Marrero-Gómez MV (2004) Kunkeliella psilotoclada (Svent.) Stearn. In: Bañares A, Blanca G, Güemes J et al (eds) Atlas y libro rojo de la flora vascular amenazada de España. Dirección General de Conservación de la Naturaleza, Madrid, p 66

Martín A, Nogales M, Alonso J, et al (2002) Restauración de los Islotes y del Risco de Famara (Lanzarote). San Cristóbal de la Laguna

Martín MC, Marrero P, Nogales M (2003) Seasonal variation in the diet of wild rabbits Oryctolagus cuniculus on a semiarid Atlantic island (Alegranza, Canarian Archipelago). Acta Theriol (Warsz) 48:399–410. https://doi.org/10.1007/BF03194178

Massó S, López-Pujol J, López-Alvarado J et al (2016) One species, one genotype: no genotypic variability in the extremely narrow endemic tetraploid Agrostis barceloi (Gramineae). Plant Syst Evol 302:609–615. https://doi.org/10.1007/s00606-016-1283-9

Mayol J, Alcover JA, Domènech O et al (2017) La cabra, espècie invasora a les Balears. Editorial Lleonard Muntaner, Palma

Mayol J, Bibiloni G (2005) Ligusticum huteri. In: de Montmollin B, Strahm W (eds) The Top 50 Mediterranean island plants: wild plants at the brink of extinction, and what is needed to save them. IUCN/SSC/Mediterranean Plant Specialist Group, Gland and Cambridge, pp 20–21

Moragues E, Manzano X, Sáez L (2015) Una illa al cim, el cim d'una illa: Singularitat i conservació de la flora vascular del Puig Major. Monogr la Soc d'Historia Nat les Balear 20:69–82

Moreno JC (2008) Lista Roja de la flora vascular española. Dirección General de Medio Natural y Política Forestal - SEBICOP, Madrid

Muñoz-Gallego R, Fedriani JM, Traveset A (2019) Non-native nammals are the main seed dispersers of the ancient mediterranean palm Chamaerops humilis L. in the Balearic Islands: rescuers of a lost seed dispersal service? Front Ecol Evol 7:161. https://doi.org/10.3389/fevo.2019.00161

Muñoz-Gallego R, Fedriani JM, Serra PE, Traveset A (2022) Non-additive effects of two contrasting introduced herbivores on the reproduction of a pollination-specialized palm. Ecology. https://doi.org/10.1002/ecy.3797

Nogales M, Marrero M, Hernández EC (1992) Efectos de las cabras cimarronas (Capra hircus L.) en la flora endémica de los pinares de Pajonales, Ojeda e Inagua (Gran Canaria). Botánica Macaronésica 19:79–85

Nogales M, Nieves C, Illera JC et al (2005) Effect of native and alien vertebrate frugivores on seed viability and germination patterns of Rubia fruticosa (Rubiaceae) in the eastern Canary Islands. Funct Ecol 19:429–436. https://doi.org/10.1111/j.0269-8463.2005.00975.x

Nogales M, Rodríguez-Luengo JL, Marrero P (2006) Ecological effects and distribution of invasive non-native mammals on the Canary Islands. Mamm Rev 36:49–65. https://doi.org/10.1111/j.1365-2907.2006.00077.x

Nogales M, Valido A, Medina FM (1995) Frugivory of Plocama pendula (Rubiaceae) by the rabbit (Oryctolagus cuniculus) in xerophytic zones of Tenerife (Canary Islands). Acta Oecologica 16:585–591

Olano JM, Brito P, González-Rodríguez ÁM et al (2017) Thirsty peaks: drought events drive keystone shrub decline in an oceanic island mountain. Biol Conserv 215:99–106. https://doi.org/10.1016/j.biocon.2017.09.008

Palombo MR, Rozzi R, Bover P (2013) The endemic bovids from Sardinia and the Balearic Islands: state of the art. Geobios 46:127–142. https://doi.org/10.1016/j.geobios.2012.10.011

Pérez de Paz J, Febles R, Férnandez-Palacios Acosta O, Olanga Corral M (2017) Flores y polen. Éxito reproductivo de las angiospermas en Canarias. Origen, evolución y conservación. Rev la Acad Canar las Ciencias XXIX:111–202

Pinya S, Lassnig N (2018) First record of free-ranging fallow deer (Dama dama) in Mallorca (Balearic Islands, Spain). Galemys, Spanish J Mammal 30:63–65. https://doi.org/10.7325/galemys.2018.n2

Pisanu S, Farris E, Filigheddu R, García MB (2012) Demographic effects of large, introduced herbivores on a long-lived endemic plant. Plant Ecol 213:1543–1553. https://doi.org/10.1007/s11258-012-0110-9

Pons A, Rullan O (2014) The expansion of urbanisation in the Balearic Islands (1956-2006). J Mar Isl Cult 3:78–88. https://doi.org/10.1016/j.imic.2014.11.004

Priddel D, Carlile N, Wheeler R (2000) Eradication of European rabbits (Oryctolagus cuniculus) from Cabbage Tree Island, NSW, Australia, to protect the breeding habitat of Gould's petrel

(Pterodroma leucoptera leucoptera). Biol Conserv 94:115–125. https://doi.org/10.1016/S0006-3207(99)00155-X
Pulido-Suárez L, Díaz-Peña F, del Pino JN et al (2021) Alteration of soil rhizobial populations by rabbit latrines could impair symbiotic nitrogen fixation in the insular alpine ecosystem of Teide National Park. Appl Soil Ecol 160:103850. https://doi.org/10.1016/j.apsoil.2020.103850
Rando JC (2003) Protagonistas de una catástrofe silenciosa. El indiferente, 14:4-15.
Rando JC (2014) Informe preliminar sobre la situación del ganado asilvestrado en la Red Natura 2000 en Canarias. Santa Cruz de Tenerife
Ricketts TH, Dinerstein E, Boucher T et al (2005) Pinpointing and preventing imminent extinctions. Proc Natl Acad Sci U S A 102:18497–18501. https://doi.org/10.1073/pnas.0509060102
Rita J (2016) Protección del patrimonio natural vs. derecho de los animales: Extirpación de cabras asilvestradas en Es Vedrà (Ibiza, Islas Baleares). Conserv Veg 20:29
Rita J, Capó M, Cursach J (2022) Eradication of rabbits from islets is essential for conservation of microinsular vegetation and narrow endangered flora: the case of Medicago citrina (Fabaceae) in s'Espartar islet (Balearic Islands, Western Mediterranean Basin). Biodivers Conserv 31:779–796. https://doi.org/10.1007/s10531-022-02362-4
Rita J, Payeras T (2006) Biodiversidad de las plantas vasculares de las Islas Baleares. Orsis Org i Sist 21:41–58
Rivera-Sánchez L (2014) Ecología trófica de ungulados en condiciones de insularidad. Universitat Autònoma de Barcelona
Rodríguez-Delgado O, Elena-Rosselló E (2006) Evolución del paisaje vegetal del Parque Nacional del Teide. Ministerio de Medio Ambiente, Madrid
Roemer GW, Donlan CJ, Courchamp F (2002) Golden eagles, feral pigs, and insular carnivores: how exotic species turn native predators into prey. Proc Natl Acad Sci U S A 99:791–796. https://doi.org/10.1073/pnas.012422499
Rosenbaum G, Lister GS, Duboz C (2002) Reconstruction of the tectonic evolution of the western Mediterranean since the Oligocene. J Virtual Explor 8:107–130. https://doi.org/10.3809/jvirtex.2002.00053
Sáez L, Fraga P, López-Alvarado J (2013) The flora of the Balearic Islands. In: Cardona E, Estaún I, Comas M, Fraga P (eds) Islands and plants: preservation and understanding of flora on Mediterranean. Consell Insular de Menorca, Maó, p 20
Sáez L, Roselló JA (2004) Ligusticum huteri (Porta) L. Sáez & Rosselló. In: Bañares A, Blanca G, Güemes J et al (eds) Atlas y Libro rojo de la flora vascular amenazada de España. Dirección General de Conservación de la Naturaleza, Barcelona, pp 204–205
Sáez L, Roselló JA, Fraga P (2017) Llibre vermell de la flora vascular de les Illes Balears. Direcció General Espais Naturals i Biodiversitat. Govern de les Illes Balears
Sáez L, Rosselló JA (2004) Agrostis barceloi L. Sáez & Rosselló. In: Bañares A, Blanca G, Güemes J et al (eds) Atlas y Libro rojo de la flora vascular amenazada de España. Dirección General de Conservación de la Naturaleza, Barcelona, pp 82–83
Sáez L, Rosselló JA (2000) A new species of Agrostis (Gramineae) in the A. alpina complex. Bot J Linn Soc 133:359–370. https://doi.org/10.1006/bojl.1999.0322
Salgado-Luarte C, Escobedo VM, Stotz GC et al (2019) Goat grazing reduces diversity and leads to functional, taxonomic, and phylogenetic homogenization in an arid shrubland. L Degrad Dev 30:178–189. https://doi.org/10.1002/ldr.3208
Santamaría L, Larrinaga AR, Latorre L, Pericàs J (2007) Herbívoros exóticos del Archipiélago de Cabrera: Bases para una estrategia de gestión basada en la minimización de impactos
Seguí J, López-Darias M, Pérez AJ et al (2017) Species-environment interactions changed by introduced herbivores in an oceanic high-mountain ecosystem. AoB Plants 9. https://doi.org/10.1093/aobpla/plw091
Sventenius E (1946) Notas sobre la flora de las Cañadas de Tenerife. Cuaderno/INIA 78:1–284
Traveset A, Nogales M, Alcover JA et al (2009) A review on the effects of alien rodents in the Balearic (western Mediterranean sea) and Canary islands (eastern Atlantic ocean). Biol Invasions 11:1653–1670. https://doi.org/10.1007/s10530-008-9395-y

Traveset A, Richardson DM (2006) Biological invasions as disruptors of plant reproductive mutualisms. Trends Ecol Evol 21:208–216. https://doi.org/10.1016/j.tree.2006.01.006

Velamazán M, San Miguel A, Escribano R, Perea R (2017) Threatened woody flora as an ecological indicator of large herbivore introductions. Biodivers Conserv 26:917–930. https://doi.org/10.1007/s10531-016-1279-3

Vives JA, Baraza YE (2010) La cabra doméstica asilvestrada (Capra hircus) en Mallorca ¿Una especie a erradicar? Galemys 22:193–205

Vogel P, Sofianidou T (1996) The shrews of the genus Crocidura on Lesbos, an Eastern Mediterranean Island. Bonner Zool Beiträge 46:339–347

Wheeler CT, Dickson JH (1990) Symbiotic nitrogen fixation and distribution of Spartocytisus supranubius on Las Canadas, Tenerife. Rev Vieraea 19:309–314

Whittaker RJ, Fernández-Palacios JM (2007) Island Biogeography. Ecology, evolution and conservation. Oxford University Press

Winkler DE, Schulz E, Calandra I et al (2013) Indications for a dietary change in the extinct Bovid genus Myotragus (Plio-Holocene, Mallorca, Spain). Geobios 46:143–150. https://doi.org/10.1016/j.geobios.2012.10.010

Wood J, Alcover JA, Blackburn T et al (2017) Island extinctions: processes, patterns, and potential for ecosystem restoration. J Environ Conserv 44:348–358. https://doi.org/10.1017/S037689291700039X