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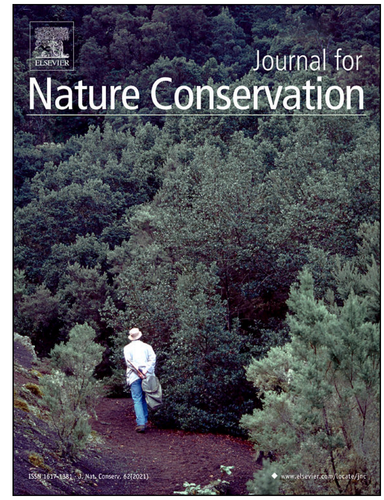

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Eradication of feral goats, not population control, as a strategy to conserve plant communities on Mediterranean islets.

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Abstract

The introduction of mammalian herbivores negatively affects insular vegetation, especially plant species with narrow distributions that are vulnerable to herbivory or that evolved in the absence of native mammal herbivores. Eradication programs have been performed on many islands worldwide, though assessment of the responses of vegetation is crucial to guarantee the success of these programs. In this study, we aimed to evaluate vegetation recovery after a reduction in the feral goat population on Es Vedrà, an islet in the Balearic Islands (Western Mediterranean Basin). We monitored nine permanent plots in three different habitats (rocky areas, grasslands, shrublands) to evaluate the variation in plant coverage, functional traits and diversity indexes over time. We obtained data for each plot by annual field sampling in mid-May of 2016 to 2019. We observed a significant recovery of the predominant species in each plant community and an increase in many functional traits. We found significant variation in taxonomic diversity in rocky areas and grasslands, but not in shrublands, and functional diversity only varied in rocky areas. Therefore, plant diversity benefited from the reduction in the goat population and functional redundancy increased in rocky areas, improving the capacity to respond against disturbances. However, the reduction in the goat population was not sufficient to preserve plant communities and negative effects reappeared in 2019, coinciding with the increase in the goat population. Therefore, absolute eradication of introduced herbivores represents a unique, efficient strategy to guarantee the ecological restoration of affected habitats in microinsular ecosystems.

Key words: invasive herbivores, microinsularity, functional ecology, conservation, island restoration

Authors contribution

M.C., J.C. and J.R. designed the experiment. All authors participated in the fieldwork and data collection. M.C. analyzed the data and wrote the first draft of the manuscript. All authors contributed to the final version of the manuscript.

Declarations

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Conflicts of interest

V. Picorelli is an employee of Institut Balear de la Natura, Conselleria de Medi Ambient i Territori (Government of the Balearic Islands). J. Rita received financial support from Conselleria de Medi Ambient i Territori (Government of the Balearic Islands).

Availability of data and material

Data and material used for this manuscript will be made available by contacting the corresponding author by e-mail.

Code availability Not applicable.

Authors’ contribution

MC, JR and JC designed the experiment; JR obtained financial support for the study; all authors sampled in the fieldwork; MC, EB and JR analyzed the data, MC wrote the first version of the manuscript and all authors collaborated in revising and formatting the definitive version of the manuscript.

Ethics approval Not applicable.

Consent to participate Not applicable.

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Introduction

Insular ecosystems have been affected by biological invasions since the arrival of humans (Gurevitch and Padilla 2004; Bellard et al. 2016) and these ecosystems are particularly vulnerable as islands harbour high rates of endemic species, refugee for threatened species and areas with interesting population genetics (Thompson 2020). Of all of the mammals introduced to islands, goats (*Capra hircus* L.) and rabbits (*Oryctolagus cuniculus* L.) are some of the most widespread species worldwide (Flux and Fullagar 1992; Capizzi 2020). The presence of introduced herbivores affects the whole ecosystem through processes such as predation of plant species, erosion, nitrification, and alteration of the soil composition (Coblentz 1978; Desender et al. 1998; Campbell and Donlan 2005) or even interfering with the breeding of marine birds (Imber et al. 2000), among other examples. Overgrazing of insular plant populations by introduced herbivores is more harmful for plant species without defences against herbivory, and in some cases, forces the plants to constrain their habitat (Pisanu et al. 2012) and even threaten critically endangered flora (Menezes de Sequeira et al. 2021). Indeed, many studies have reported that insular endemic species are highly vulnerable to herbivory due to a lack of defences against introduced herbivores (Bowen and Van Vuren 1997), a low tolerance to herbivory (Barton 2016; Capó et al. 2021b) or high palatability (Cubas et al. 2019).

Domestic goat herds have been widely introduced to islets that surround other larger islands or mainlands to use the islets as breeding areas (Mayol et al. 2017). In fact, many islets have been severely affected by goat herbivory (Daly 1989), and their small dimensions do not allow plant species to escape from herbivory; thus, plant communities on islets are more impacted by herbivory than on larger islands (Campbell et al. 2004). In this sense, evaluation of how islets communities respond to herbivores is crucial to understand how the presence of goats affects insular ecosystems (Carrete et al. 2009;

Arévalo et al. 2011). Environmental management has focused on eradicating goats in many parts of the world in order to restore the natural equilibrium in islands (Campbell and Donlan 2005), and these efforts have been especially intense in the Mediterranean Basin (Capizzi 2020). To date, a total of 139 attempts to eradicate mammalian herbivores have been performed on 107 Mediterranean islands and islets (Capizzi 2020), including eradications of feral goats, mice, black rats and European rabbits. However, ensuring total eradication of introduced mammals is not easy and sometimes a small number of individuals can still remain in the area (Scowcroft and Hobdy 1987; Zavaleta et al. 2001; Beltran et al. 2014), and thus the recovery of the vegetation might not succeed in the long-term (Campbell and Donlan 2005).

Despite the fact that plant richness may remain unaltered or even increase with goat grazing (Fernández-Lugo et al. 2011), herbivores usually contribute to the replacement of native island endemics by widespread generalist taxa (Gizicki et al. 2018) or even invasive species (Abe et al. 2011). Many studies have focused on evaluating the effects of goat herbivory on plant coverage and taxonomic diversity. However, less attention has been paid to functional diversity (i.e., the distribution of species and their abundances in the functional space of the whole community) (Gatica et al. 2020), which is an important indicator of ecosystem function and services (Díaz and Cabido 2001; Mouillot et al. 2013). Several indices have been proposed to assess various aspects of functional diversity (e.g., functional richness, evenness, divergence and dispersion) (Villéger et al. 2008; Laliberte and Legendre 2010) and these indices are more sensitive to disturbances than other indices that take into account the relative abundance of species, such as functional evenness (i.e., the regularity of the distribution and relative abundance of species in the functional space of a community) and divergence (i.e., the proportion of total abundance supported by species with the most extreme trait values within a community) (Laliberte and Legendre 2010; Mouillot et al. 2013). For example, (Salgado-Luarte et al. 2019) reported that goat grazing leads to taxonomical and functional homogenization and causes overall community impoverishment as goats act as a habitat filter in arid ecosystems. Moreover, (Chillo et al. 2017) showed that increased livestock grazing led to higher functional redundancy, as several species seem to share similar traits.

The management of introduced goats is currently a key issue on the Balearic Islands (Western Mediterranean Basin) and its impact on vegetation has recently been evaluated (Rivera et al. 2015; Bartolomé et al. 2019; Limpens et al. 2020). Herds of goats are mainly located in the mountains of the north-west of Mallorca, with other groups located on the east of Mallorca and also on Menorca (Mayol et al. 2017). A very fluctuant herd was also present on Es Vedrà, an islet located on the Western coast of Eivissa. This islet was used by its owners as a hunting area for feral goats a few decades ago until abandonment of the practice, which led to the spontaneous disappearance of the feral herd that remained on the islet. However, a new introduction of feral goats occurred in the 90s without restarting the hunting practice, which led to the uncontrolled growth of the herds. Some years later, after the declaration of the Natural Reserve of Es Vedrà, es Vedranell i els illots de Ponent (Decree 24/2002, BOIB no. 23, 21/02/2002), the environmental authority decided to eradicate feral goats from the islet. The removal was partially executed during 2016 and the population diminished from ca. 70 to four individuals. However, motivated by protests from animal groups, total eradication was interrupted by a legal judgement that, as a precautionary measure, prohibited the extraction of the last goats to ensure all guarantees of animal health were fulfilled. Rapid growth of the population subsequently occurred until 2019, when the population had reached 20 individuals. The same year of the eradication attempt, we performed monitoring of permanent plots to evaluate vegetation changes over the short-term. Specifically, we aimed (i) to evaluate how plant coverage in different communities responds to a reduction in the goat population in the short-term, (ii) to study the effect of reducing the goat population on taxonomic and functional diversity, and (iii) to confirm whether the reduction in the grazing impact is sufficient to recover plant coverage and diversity in a microinsular ecosystems or, on the contrary, whether complete eradication is necessary.

Materials and Methods

Study site

The study was carried out on the islet of Es Vedrà (38º52'N, 1º11'E) located on the west coast of Eivissa island (Balearic Islands, Western Mediterranean Basin; Fig. 1). The islet covers 63 ha and rises to 382 m a.s.l., it is located 1.82 km away from the main island, and is included in a Natural Reserve (Decree 24/2005, BOIB n. 23 21/02/2002). Bibiloni et al. (2003) described eight habitats across the islet: (1) coastal halophyte chamaephytes (dominated by *Limonium ebusitanum* (Font Quer) Font Quer), (2) nitro-halophile succulent chamaephytes (dominated by *Suaeda vera* Forsskal ex J.F. Gmelin), (3) shrublands (dominated by *Pistacia lentiscus* L.), (4) coastal cliffs (dominated by *Withania frutescens* (L.) Pauquy), (5) rocky areas with shrubs (dominated by *W. frutescens)* (6) grassland and rupicolous communities rich in endemic species and (7) eroded slopes (dominated by *Brachypodium retusum* (Pers.) Beauv.). The eighth habitat, which consists of rupicolous communities dominated by *Helichrysum crassifolium* D.Don, has disappeared from the islet (pers. obsv.). Several human impacts have occurred in the past, such as the use of the islet as a hunting area, felling juniper trees (*Juniperus phoenicea* L. ssp. *turbinata* (Guss.) Nyman) and the involuntarily introduction of rats

(*Rattus rattus* (Linnaeus, 1758)); however, the islest has never been cultivated or constructed, and no fires occurred in recent times. Thus, except for feral goats impacts, plant communities in Es Vedrà are relatively well preserved. Despite fossils of ancient mammal herbivores being recorded in Mallorca and Menorca (mainly the bovid *Myotragus balearicus* (Bate, 1909), they are absent from Eivissa, Formentera and their adjacent islets.

Field surveys

Nine permanent plots were set in the three main habitats of the islet selected from (Bibiloni et al. 2003): rocky areas with shrubs dominated by *W. frutescens*, grasslands dominated by *Trachynia distachya* (L.) Link, and shrublands dominated by *P. lentiscus*. Four 5 × 5 m plots were set in rocky areas in 2015, and three and two 10 × 10 m plots were set in grasslands and shrublands, respectively, in 2016 (Table 1). The plots differed in size due to the particularities of each zone. Each plot was sampled to compile data on plant richness and plant coverage (see below) in mid-May from 2016 to 2019. It was not possible to set monitoring plots fenced out of the feral goats due to accessibility limitations, and we thus focused on vegetation changes through time in response of different goat densities.

Plant richness

A complete inventory of each plot was performed by species identification in the field. In cases with complex taxonomical features, samples were taken to the laboratory to determine the species using (Gil and Llorens 2017). Nomenclature followed the Plants of the World Online criteria (POWO 2021). We subsequently obtained data on the life form of each species following the criteria of the Virtual Herbarium of the Western Mediterranean (Herbari Virtual del Mediterrani Occidental 2019).

Plant coverage

To evaluate the coverage of each species, a 20-m linear transect crossing the diagonal of each plot was established and the presence of each species every 10 cm along the transect was recorded yearly from 2015 to 2019 (in total, we collected 200 sampling points per plot and year). Identical linear transects were repeated every year, from one vertex of the plot to the opposing corner creating a diagonal. In the four plots with smaller dimensions installed in rocky areas, two linear transects crossing both diagonals were used to achieve the 20-m length and 200 sampling points.

Taxonomic diversity

Species coverage was calculated by assessing the number of appearances along the transect. Species from the inventories that did not appear in the transect were assigned an appearance of < 0.5, which represents a cover of 0.25% (Cursach et al. 2020). For each plot per year, we calculated (i) the species richness (S) as the total number of species in each plot inventory, (ii) Shannon's diversity index (S) as a measure of plant diversity (Shannon 1948) and (iii) Pielou's evenness as a measure of plant evenness (Pielou 1975).

Functional traits

For all plant species found in all plots, we compiled data on five functional traits from the BROT (Tavşanoğlu and Pausas 2018) and TRY (Kattge et al. 2020) databases included in the 'TR8' package using the 'tr8' function (Bocci 2015), as well as from personal knowledge. Functional traits selected for the analysis were life span (very short, < 2 yrs.; short, 2-5 yrs.; medium, 5-25 yrs.; long 25-150 yrs. and very long, > 150 yrs.), palatability (low, when toxic or protective structures are present; medium, when the plant is not usually eaten; and high, when predation marks are abundant), and reproductive traits such as pollination syndrome (entomophilous/not entomophilous), seed dispersal (zoochory/other), and annual seed production (rarely, seeds rarely produced; few, < 50 seeds; medium, 50-500 seeds; many, > 500 seeds) (Cursach et al. 2020).

Functional diversity

Using the species abundance data and functional traits described above, we calculated the following indices to describe plant functional diversity: (i) functional richness (FRic), as the functional trait range occupied by all trait combinations in the community, (ii) functional evenness (FEve), which reflects the homogeneity of the distribution of traits and (iii) functional divergence (FDiv), a measure of spreading-out/clustering in the functional space (Pillar et al. 2013).

Statistical procedures

Taxonomic diversity indexes were calculated using the '*diversity'* and *'specnumber'* functions of 'vegan' package (Oksanen et al. 2008). The functional indices were determined using the '*dbFD'* function of the 'FD' package (Laliberte and Legendre 2010). All statistical procedures were performed using R software version 3.5.0 (R Core Team 2019). Generalized additive mixed models (GAMM) were used to evaluate coverage changes using the '*gamm'* function of the '*mgcv*' package (Wood 2011), in which plant coverage was used as a response variable, years as a smoothing term and plot as a random factor. In the case of taxonomic and functional diversity indexes, both indices were considered as response variables in their respective models, years was included as a smoothing term and plot as a random factor. All analyses were also executed separately for each habitat, life form or trait and significant differences were tested using '*Anova'* function of the '*car'* package (Fox and Weisberg 2019). Graphs were generated using the '*ggplot*' function of '*ggplot2*' package (Wickham 2016).

Results

Plant coverage changes after herbivore reduction

Plant coverage changed significantly after the reduction in the goat population in 2016 ($\square^{23}$= 40.59, *P*-value < 0.001). Specifically, plant coverage increased in rocky areas and grasslands one year after the eradication attempt. The plant overage in rocky areas was maintained at the same level in the following years (Fig. 2), but decreased slightly in grasslands by 2019. The vegetation coverage of shrublands community did not significantly change after the reduction in the goat population, though an increasing trend was observed.

Focusing on how each life form varied after the reduction in the goat population, differences were observed for the predominant life forms in rocky areas and grasslands, but not for shrublands (Fig. 3), and these differences reflected the trends observed for total plant coverage. In rocky areas, the coverage of phanerophytes, the predominant life form, increased after the reduction in herbivores, while the coverage of other life forms remained at the same levels. The coverage of therophytes increased in grasslands after herbivore reduction. However, no variation in any life form was observed for shrublands over time, similarly to the results for total plant coverage.

In order to evaluate which species increased their coverage after the reduction in the goat population, specific analyses were performed for all species (Table S1); significant differences were observed for many species. Seven (44%) species in rocky areas, 13 (24%) in grasslands and four (22%) in shrublands significantly increased their coverage. Three species with an initial abundance higher than 10% significantly recovered after the reduction in the goat population: *W. frutescens* in rocky habitats, and *Diplotaxis ibicensis* (Pau) Gómez Campo and *T. distachya* in grasslands. Nevertheless, the recovery of both *W. frutescens* and *D. ibicensis* was interrupted in 2019, when the goat population increased up to 20 individuals, indicating that the herbivory pressure was affecting the plant communities again.

Taxonomical and functional diversity

Taxonomic diversity varied over the years in rocky communities and grasslands after the reduction in the goat population, but not in shrublands. Rocky areas showed a higher richness in 2019 and increased on Shannon diversity and Pielou's evenness indexes in 2018. However, latter indexes decreased in 2019 reaching the values from 2016. In grasslands, richness increased in 2019 and no variation was found in the other indexes (Fig. S1; Table 2A). In the case of functional diversity, functional richness increased while functional divergence decreased over the years in rocky areas, functional evenness decreased in shrublands, and no differences were observed for grasslands (Fig. S1; Table 2B).

After the reduction in the goat population, the coverage of plants varied in different directions depending on their functional traits in many habitats (Fig. 4). Species with high palatability increased after the reduction in the goat population (e.g., *D. ibicensis*). At the same time, species of medium palatability increased in grasslands, while low palatability species increased in shrublands. Moreover, entomophilous species increased in all plant communities and zoochorous species increased in rocky areas and grasslands. No variation was found for high seed-producer species; coverage increased in species that produce 50-500 seeds per fruit only in grasslands and the same pattern was observed in species that produce few seeds (less than 50 per fruit) in both rocky areas and grasslands. Many functional traits showed an initial increasing trend but returned to basal values in 2019, especially in grasslands.

Discussion

We reported that plant communities in Es Vedrà recovered after reduction of the goats population. Rocky habitats and grasslands exhibited a recovery in plant coverage in 2017 after the exhaustive reduction in the goat population in 2016 (from ca. 70 to four). Plant coverage recovery after the eradication of goats is commonly observed in many ecosystems (Bullock et al. 2002; Beltran et al. 2014). Moreover, goats exert more harmful effects in insular ecosystems than other areas (Bowen and Van Vuren 1997; Cubas et al. 2019). Additionally, palatable shrubs in rocky areas are selected more frequently than other less-palatable species (Limpens et al. 2020), and high selection pressure significantly affects pollination and fruit production (Traveset and Richardson 2006). Predominant shrubs can act as nurse for other species from the same community when intense herbivory occurs (Maestre et al. 2003). In this sense, in areas where the predominant species are severely damaged by introduced herbivores, the disappearance of their nursery indirectly affects the population stability of other species. On the contrary, shrublands with high abundance of non-palatable species are less affected by introduced herbivores (Baraza et al. 2006). Vegetation changes observed can also be influenced by inter-annual variation in climatic conditions (Espigares and Peco 1993; Fernández-Moya et al. 2011), which could have enhanced the short-term recovery of some species, particularly therophytes.

The most strongly recovered species were *D. ibicensis* and *W. frutescens*; these species significantly increased their coverage one year after the goat population reduction, but then decreased again once the population of goats rose to 20 individuals in 2019. Indeed, observations taken in the 80s prove that the abundance of both species was much higher before the goats were introduced again, indicating the potential for recovery of vegetation if goats are completely eradicated (pers. obsv.). Both of these species were severely affected because they are more abundant and palatable than other species and, therefore, have a higher probability of being consumed by goats (Mauricio 2000; Baraza et al. 2006). Regarding *D. ibicensis,* the annual lifespan and high seed production of this species allow it to produce a large seed-bank in a short period of time. Thus, this species could germinate rapidly once herbivores were reduced, and its coverage notably increased in grasslands (Fig. 5).

Coexistence with herbivores depends on the capacity of plants to resist or tolerate herbivory (Strauss and Agrawal 1999; Mauricio 2000), and though their fitness may be negatively affected, plants can still regrow and survive in the presence of herbivores (Small 1996). Our results indicate that *W. frutescens* is tolerant to herbivory and is able to survive in areas with a high density of goats, when herbivory pressure decreases, the species resprouts and its coverage increases (from 44% of plant coverage in 2016 to 70% in 2018). Additionally, *T. distachya,* a graminoid therophyte, recovered one year after the reduction in the goat population and was not affected by the increase in the goat population in 2019. Nevertheless, we predict that this species would be affected over the medium term, as observed for other Poaceae species that are browsed (Beltran et al. 2014). *Pistacia lentiscus* was less affected by herbivory pressure, and was the predominant species in shrubland habitats; its coverage was always high and did not change over time. This shrub contains a high concentration of tannins and its palatability is low (Navon et al. 2020). For this reason, *P. lentiscus* is not selected by goats if other higher quality resources are available.

Other species that were abundant in the 80s before the goats were present and recovered slowly across the islet after the goat population reduction include the narrow endemic species *Teucrium cossonii* D. Wood ssp. *punicum* Mayol, Mus, Rosselló & N. Torres and *Santolina vedranensis* (O.Bolòs & Vigo) L.Sáez, M.Serrano, S.Ortiz &

R.Carbajal (pers. obsv.). Indeed, we detected the reappearance of the former species in one permanent plot in 2019, and the latter resprouted in many sites of the island (pers. obsv.). Also, this regrowth capacity suggests these species are tolerant to herbivory, but the high density of goats over several years affected the populations of these endemic species and limited their occurrence to rock fissures and cliffs where goats could not access. Therefore, their ability to regrow after herbivory explains how both species needed less time to recover than other non-tolerant coexisting species (Strauss and Agrawal 1999). Therefore, we predict that both *T. cossonii* and *S. vedranensis* would become widespread across the islet in the medium- to long-term if herbivores were completely eradicated. Similarly, *Biscutella ebusitana* Rosselló, N. Torres & L. Sáez, another narrow endemic species present in the islet that is highly predated by goats, was isolated in inaccessible areas for many years and expanded after reduction of the goat population. We expect to observe similar patterns for other rupicolous species, such as *Silene hifacensis* Rouy ex Wilk. and *Helichrysum crassifolium* D.Don.

Richness, Shannon diversity and Pielou's evenness varied depending on the habitat, and a long-term study is necessary to confirm the general trends. However, we observed a significant increase of Richness and Shannon diversity in rocky areas and grasslands in parallel to the increase in coverage in these two habitats. On the contrary, no significant differences were observed in shrublands, indicating that diversity did not significantly change in the short-term, in coherence with the small changes observed in this habitat after the reduction of the goat population. This observation is not rare, as long-term analysis are required to detect changes in taxonomic diversity (Garcillán et al. 2008; Gizicki et al. 2018).

On the other hand, the reduction in the goat population led to an increase in palatable, entomogamous and zoochorous species, and species with different lifespans responded differently depending on the habitat. Interestingly, even low-palatability species increased after reduction of herbivores in shrublands, which is considered a red flag to detect overgrazing in natural areas (Capó et al. 2021a). Indeed, grazing modifies the functional traits present in each habitat (Peco et al. 2005). The recovery of plants with different functional traits allowed the ecosystem to improve its function in interactions such as pollination and seed dispersal. Functional diversity significantly varied in rocky areas, where functional richness increased (i.e., the functional trait range occupied by all trait combinations increased) and functional divergence decreased (i.e., increased trait overlap of dominant species). The decrease in functional divergence results in higher functional redundancy, which may increase community resilience to disturbances (Pillar et al. 2013).

As a general trend, the species that increased their abundance and functional traits varied after the reduction in herbivores (Fig. 6). Nevertheless, the collapse of many variables, coinciding with the increase in the goat population, was already noticeable in 2019. Indeed, only four of ca. 70 goats remained in the islet after the exhaustive reduction, but the population increased to 20 by 2019. This rapid recovery indicates the goat population will probably reach high densities in a few years, leading to a return in the degradation processes of the ecosystem that cause loss and transformation of plant communities. For this reason, and as reported in other islands worldwide (Campbell and Donlan 2005; Capizzi 2020), complete eradication of feral goats represents the only option to preserve the natural plant communities in microinsular ecosystems over the long-term.

Conclusions

The reduction in the goat population led to a short-term recovery of plant communities, especially for dominant species such as *W. frutescens* in rocky habitats and *D. ibicensis* in grasslands. On the contrary, coverage of non-palatable shrubs such as *P. lentiscus* did not significantly increase, though other highly palatable minority species recovered significantly in shrublands. The response to the reduction in the goat population was not only limited to plant coverage, but also extended to functional traits and diversity indexes: taxonomic diversity and functional richness increased due to the appearance of species with new traits, while functional divergence decreased, which may increase community resilience against disturbances through higher functional redundancy. In parallel with the rapid increase in the goat population by 2019, the predominant species exhibited the opposite trend and retrogression was observed. Overall, we conclude that recovery of plant communities occurs in the short-term when introduced herbivore populations are reduced, and the initial trends can be used to evaluate the patterns of community recovery in the future. However, if herbivores are not completely eradicated, their impact reappears a few years later. Therefore, complete eradication of herbivores is required to protect microinsular ecosystems and short-term monitoring must be conducted to assess plant recovery trends.

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Fig. captions

Fig. 1. Location of the study site in the Western Mediterranean basin. The islet is located off the Western coast of Eivissa (Balearic Islands).

Fig. 2. Variation in the total plant coverage in each habitat over time. Non-significant differences are marked as ‘ns’ and the strength of significant changes is marked with asterisks and p-values. Habitats studied were rocky areas (n = 4), grasslands (n = 3) and shrublands (n = 2).

Fig. 3. Variation in plant coverage over time for each habitat. Plant species were classified by life form (chamaephytes, geophytes, hemicryptophytes, phanerophytes and therophytes). Non-significant differences are marked as ‘ns’ and the strength of significant changes is marked with asterisks (*** $P < 0.001$; ** $P < 0.01$; * $P < 0.5$). The habitats studied were rocky areas (n = 4), grasslands (n = 3) and shrublands (n = 2).

Fig. 4. Temporal changes in all functional traits analyzed from 2016 to 2019. P-values are listed; non-significant differences are marked as ‘ns’ and the strength of significant changes is marked with asterisks (*** $P < 0.001$; ** $P < 0.01$; * $P < 0.5$). The habitats studied were rocky areas (n = 4), grasslands (n = 3) and shrublands (n = 2).

Fig. 5. Increase in *Diplotaxis ibicensis* coverage in grasslands after the reduction in the goat population. Pictures were taken in May 2016 (A) and May 2017 (B) in the same place facing in the same direction.

Fig. 6. Variation in coverage for total plants separated by functionality over time for each plant community. Number of goats censused during January-March is indicated below each year.

Fig. S1. Temporal changes in the taxonomic and functional diversity of the three studied habitats from 2016 to 2019. Error bars indicate standard error. Letters indicate differences between groups and non-significant differences are marked as ‘ns’, Tukey post-hoc test.

Table 1. Description and characteristics of the permanent plots installed to evaluate changes in plant coverage and taxonomical and functional diversity.

Table 2. Taxonomical and functional diversity indexes used to evaluate richness and evenness. Non-significant differences are marked as ‘ns’ and the strength of significant changes is marked with asterisks (*** $P < 0.001$; ** $P < 0.01$; * $P < 0.5$).

Table S1. Species list of each habitat, including mean annual abundances from 2016 to 2019 and analysis of the variance of their coverage over time. Scarce species found in inventories but not in transects were not included. Non-significant differences are marked as ‘ns’ and the strength of significant changes is marked with asterisks (*** $P < 0.001$; ** $P < 0.01$; * $P < 0.5$). All species detected were native.

Conflicts of interest

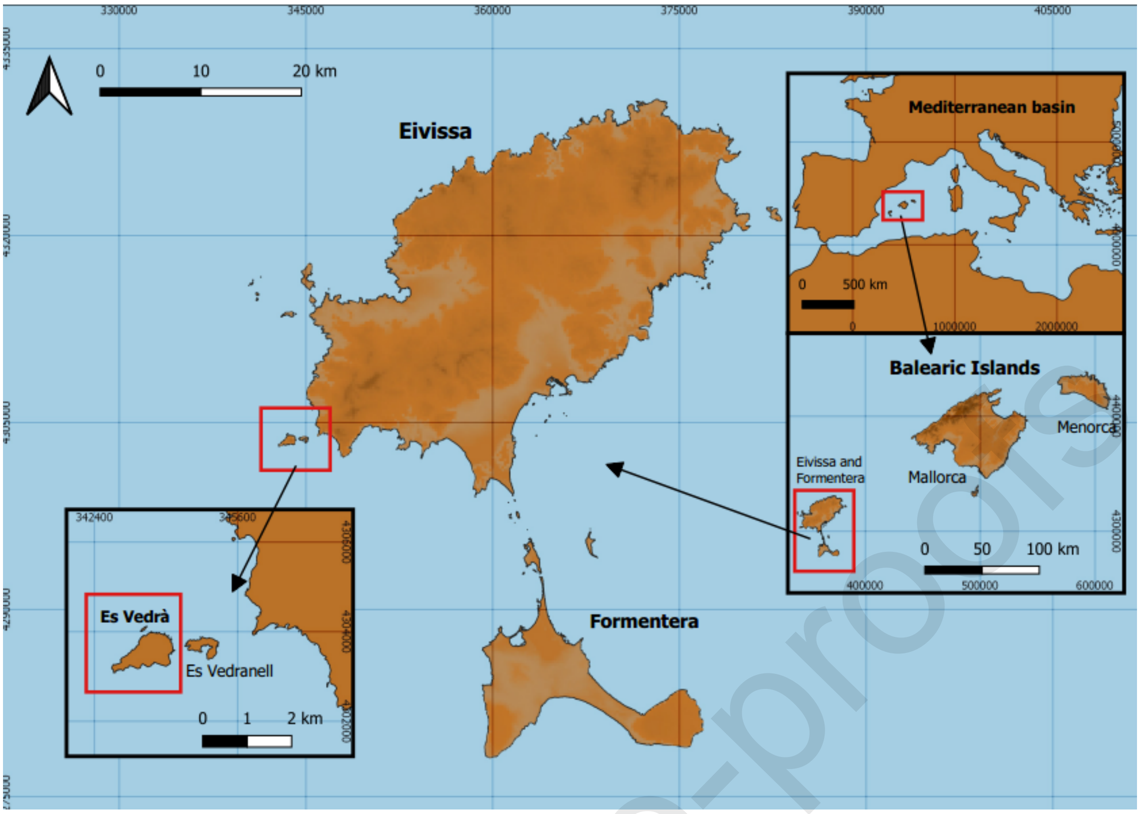
V. Picorelli is an employee of Institut Balear de la Natura, Conselleria de Medi Ambient i Territori (Government of the Balearic Islands). J. Rita received financial support from Conselleria de Medi Ambient i Territori (Government of the Balearic Islands).

Table 1. Description and characteristics of the permanent plots installed to evaluate changes in plant coverage, and taxonomical and functional diversity.

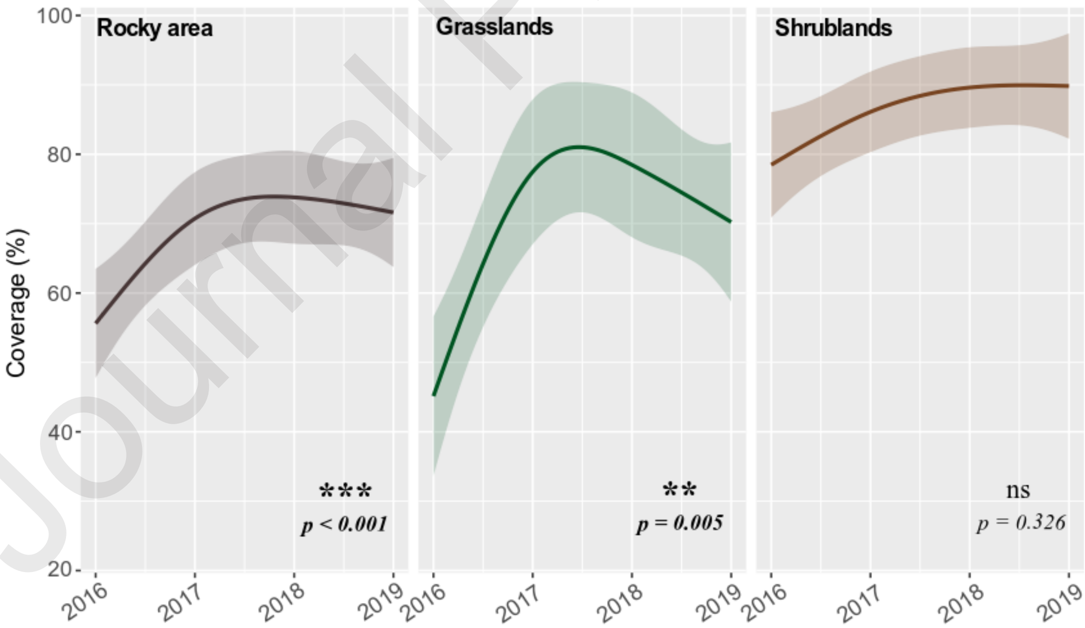
Code	Elevation and orientation	Habitat type	Dominant species
P1	55 m, South	Rocky areas, abundance of small shrubs	*Whitania frutescens* (L.) Pauquy
P2	55 m, South	Rocky areas, abundance of small shrubs	*Whitania frutescens* (L.) Pauquy
P3	55 m, South	Rocky areas, abundance of small shrubs	*Whitania frutescens* (L.) Pauquy
P4	55 m, South	Rocky areas, abundance of small shrubs	*Whitania frutescens* (L.) Pauquy
P5	80 m, West	Soil and rocks, abundance of grasses. High erosion risk.	*Trachynia distachya* (L.) Link *Convolvulus althaeoides* L. *Suaeda vera* Forsskal ex J.F. Gmelin
P6	80 m, West	Soil and rocks, abundance of grasses. High erosion risk.	*Ballota hirsuta* Benth. *Trachynia distachya* (L.) Link
P7	85 m, West	Soil and rocks, abundance of grasses and small shrubs. High erosion risk.	*Trachynia distachya* (L.) Link *Erodium chium* (L.) Willd. *Parietaria judaica* L.
P8	40 m, North	Soil areas with abundance of big-size shrubs. High slope but low erosion risk.	*Pistacia lentiscus* L. *Suaeda vera* Forsskal ex J.F. Gmelin
P9	35 m, North	Soil areas with abundance of big-size shrubs. High slope but low erosion risk.	*Pistacia lentiscus* L. *Diplotaxis ibicensis* (Pau) Gómez Campo *Suaeda vera* Forsskal ex J.F. Gmelin *Drimia maritima* (L.) Stearn

Table 2. Taxonomical and functional diversity indexes used to evaluate richness and evenness. Non-significant differences are marked as 'ns' and the strength of significant changes is marked with asterisks (*** P < 0.001; ** P < 0.01; * P < 0.5).

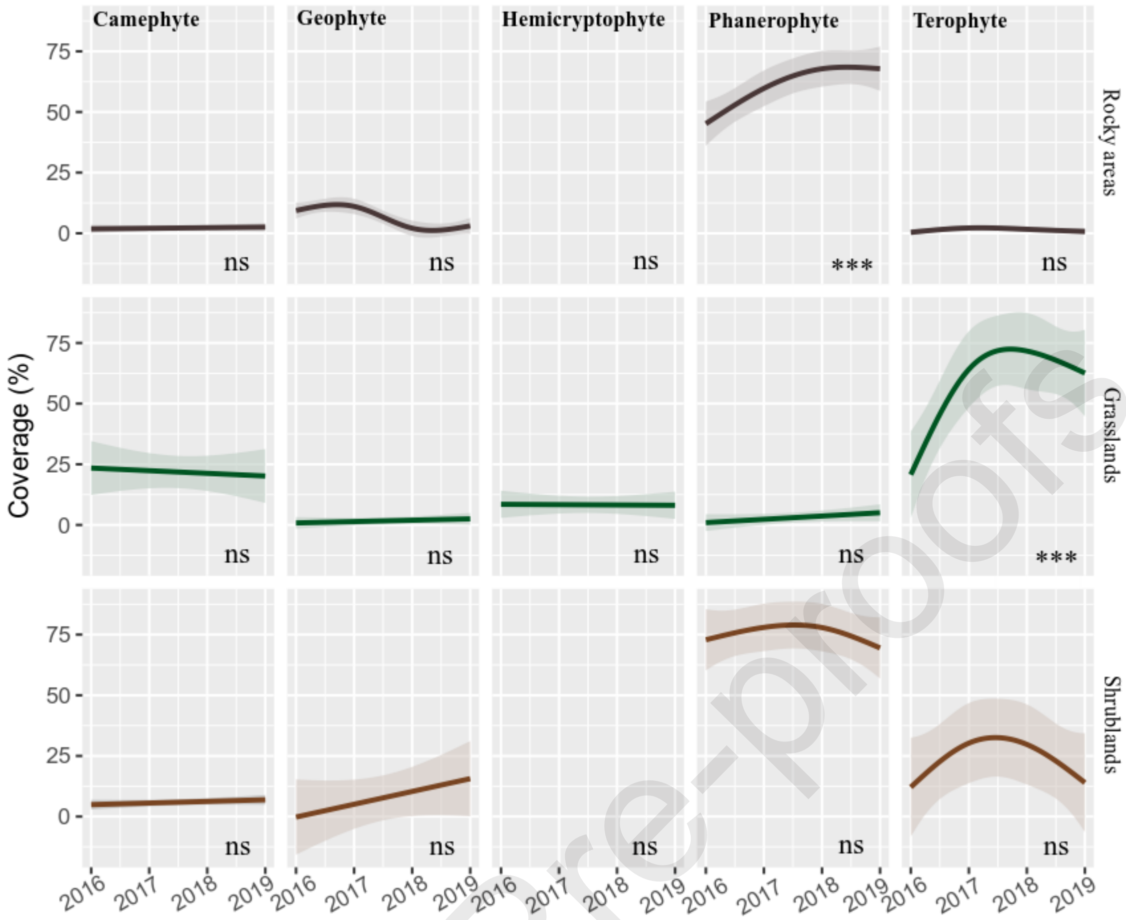
(A) Taxonomical diversity	**Rocky areas**	**Grasslands**	**Shrublands**
Richness (S)	**< 0.001 *****	**0.009 ****	0.297 ns
Shannon (H)	**0.004 ****	0.197 ns	0.567 ns
Pielou evenness (J)	**< 0.001 *****	0.593 ns	0.563 ns
(B) Functional diversity			
Functional Richness (FRic)	**0.018 ***	0.970 ns	0.295 ns
Functional Evenness (FEve)	0.861 ns	0.268 ns	**< 0.001 *****
Functional Divergence (FDiv)	**< 0.001 *****	0.253 ns	0.747 ns

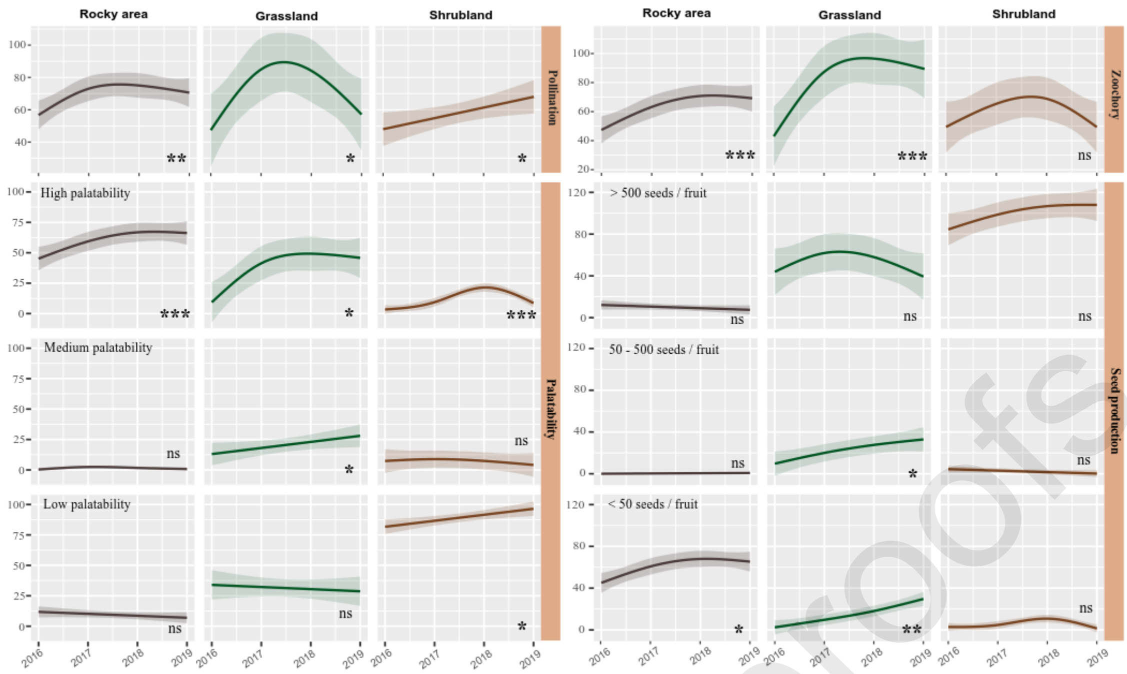


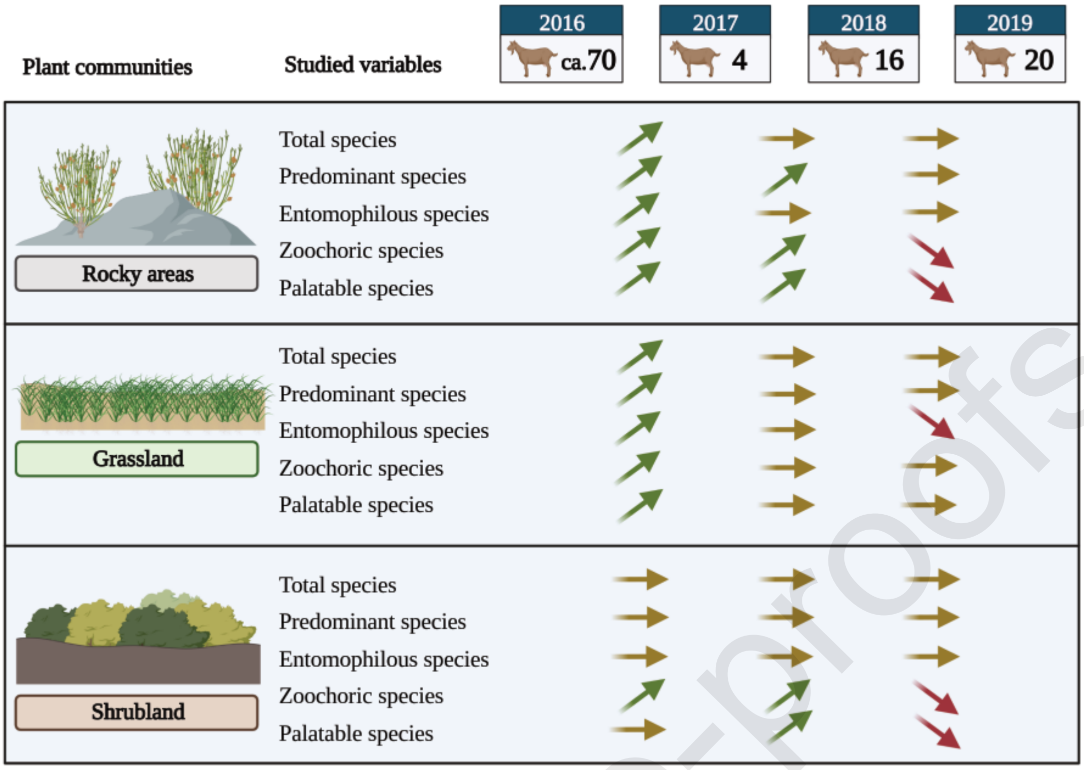
0
10
20 km
Eivissa
Mediterranean basin
0
500 km
Balearic Islands
Menorca
Mallorca
Eivissa and
Formentera
0
50
100 km
Es Vedrà
Es Vedranell
0
1
2 km
Formentera



Rocky area
Grasslands
Shrublands
Coverage (%)
100
80
60
40
20
***
p < 0.001
**
p = 0.005
ns
p = 0.326
2016
2017
2018
2019


Camephyte
Geophyte
Hemicryptophyte
Phanerophyte
Terophyte
Rocky areas
Grasslands
Shrublands
Coverage (%)
75
50
25
0
ns
***
2016
2017
2018
2019


Rocky area
Grassland
Shrubland
Pollination
Zoochory
High palatability
Medium palatability
Low palatability
Palatability
> 500 seeds / fruit
50 - 500 seeds / fruit
< 50 seeds / fruit
Seed production
2016
2017
2018
2019


Plant communities
Studied variables
2016
ca.70
2017
4
2018
16
2019
20
Rocky areas
Grassland
Shrubland
Total species
Predominant species
Entomophilous species
Zoochoric species
Palatable species