Feral pigeons as a nest competitor for a small seabird

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Abstract

Due to their life-history traits, the petrels are particularly sensitive to predation by introduced species. Therefore, many populations have constricted their original breeding distribution range, currently only occupying predator-free sites. In this scenario, interspecific competition for nesting sites can be detrimental for the petrel' conservation. Here, we evaluate how the presence of introduced mammals (cats *Felis catus* and rats *Rattus* spp.) and potential competitors for nest sites (Cory's shearwaters *Calonectris borealis* and feral rock pigeons *Columba livia*) shape the distribution, breeding density, and breeding performance of the Bulwer's petrel *Bulweria bulwerii* on Tenerife, the largest and most densely populated of the Canary Islands. We estimated nest density, assessed the role of nest location and nest characteristics on breeding success, and determined causes of breeding failure by exotic predators and competitors. Nest density was higher in predator-free colonies on marine rocks. Cat presence was the best predictor for nest density, while presence or abundance of competitors had no correlation to nest density. Breeding success varied between years and colonies, but was not related to nest characteristics. Of the unequivocally determined causes of breeding failure, pigeon competition for nests was the most frequent (7.3%), followed by rat predation (6.3%). We also compared petrel and pigeon nest cavities and found a considerable overlap in nesting niche. Our study provides insight on an overlooked impact of the invasive rock pigeon: nest competition with small seabirds. We encourage more research on the effects of pigeons on nest density, disease and pathogen transmission, and vegetation changes within petrel colonies.

Introduction

Seabirds and, particularly, petrels (including shearwaters, and storm-petrels) occur in vast ocean areas, but their breeding colonies are usually restricted to islands which are tiny in comparison with their large pelagic habitat (Brooke 2018). The restricted breeding grounds are thought to be a consequence of predation. Predation pressure is generally lower on islands than on the mainland, although humans have introduced many predators worldwide. Petrels are extremely sensitive to predation by introduced species on their breeding grounds (Rodríguez et al. 2019). So, invasive species drive seabird local extinctions and restrict seabird distribution to predator-free sites (Spatz et al. 2014, 2017).

The breeding density of birds is usually limited by the availability of nesting sites and, for cavities-nesting bird communities, cavities are a limited resource (Newton 1994). Many seabirds, especially petrels, nest underground and share nesting grounds with other species. Under this scenario, sympatric species fiercely compete for favourable nesting sites, with the smaller species usually being defeated (Ramos et al. 1997; Villard et al. 2006; McClelland et al. 2008; Sato et al. 2010), although differences in micro habitat or nest site characteristics can partially alleviate interspecific competition (Sullivan and Wilson 2001; Bourgeois and Vidal 2007; Troy et al. 2016).

Our knowledge on interspecific interactions between petrels and other non-petrel native species is limited. Evidence suggests that competition for nesting holes have little effect on petrels under natural conditions

(Rodríguez et al. 2019). However, when native species numbers increase as a result of human actions, interspecific competition can be devastating for conservation of threatened petrel populations, e.g. the nest competition of White-tailed Tropicbird *Phaethon lepturus* hampered the recovery of the endangered Bermuda petrel *Pterodroma cahow* (Madeiros et al. 2012). Future research on interspecific interactions must be further intensified and focused on to identify problematic species for endangered petrels, because this basic information is still unavailable to many petrel species (Rodríguez et al. 2019).

In the Canary Islands, seven Procellariiform species breed currently. All of them, except the Cory's shearwater *Calonectris borealis*, present threatened and declining small populations (Lorenzo 2007). Small species show small and patchily distributed breeding colonies, mainly located on predator free islets and marine rocks which are difficult to access (Lorenzo 2007). Due to these sites small size, suitable breeding holes are limited. So, competition for nests may occur as in other nearby locations (Ramos et al. 1997; Bried and Bourgeois 2005).

The rock pigeon *Columba livia* is an invasive species introduced worldwide (https://www.cabi.org/isc/datasheet/87913), which has been eradicated from the Galapagos Islands to protect its unique biodiversity (Phillips et al. 2012). This pigeon, native to Europe and the Canary Islands, has suffered an important genetic introgression with domestic pigeons during the last few centuries (Johnston and Janiga 1995; Lorenzo 2007; Giunchi et al. 2020). Thanks to its high reproductive rates and behavioural plasticity, feral pigeons can become pests (Johnston and Janiga 1995). The negative ecological impacts of feral pigeon populations include transmission of infectious diseases and pathogens (Foronda et al. 2004; Burt et al. 2018; Mori et al. 2019), changes in chemical soil properties by means of the acidity of its excrement (Spennemann and Watson 2017), and competition with native species for resources such as food or nesting holes (Forero et al. 1996; Hernández-Brito et al. 2014). Despite its impacts, field studies are scarce and the few available focus primarily on their role as disease vectors.

Here, we assess the role of pigeons on the nesting density and breeding performance of a small seabird, the Bulwer's petrel *Bulweria bulwerii*, on a densely human-populated island of the Canaries. To compare the pigeons' role with those of introduced predators and other nest competitor, we also evaluated the presence of cats *Felis catus* and rats *Rattus* spp., and the abundance of Cory's shearwaters. During 2017–2020, we (i) estimated nest density in colonies, (ii) assessed the impact of nest location and nest characteristics on breeding success, and (iii) determined causes of breeding failure by exotic predators and competitors. We also compared physical characteristics of nest-cavities used by petrels and pigeons to assess nesting niche segregation.

Material And Methods

Study area and species

The study was conducted on Tenerife, the largest and the highest (2,034 km^2 and 3,718 m a.s.l.) of the Canary Islands (Fig. S1). The coastline (342 km) is predominantly rocky with boulder shores, cliffs up to 300 m height, and small marine rocks in the north coast. In 2019, the local human population was around 949,471 inhabitants, but as the island's economy is highly based on the tourism industry, each year several millions of visitors are received (Instituto Canario de Estadística, www.gobiernodecanarias.org/istac/).

The Bulwer's petrel is a small pelagic procellariiform (75-130 g), with a disjointed pan-oceanic distribution in tropical and subtropical waters of the Pacific, Indian, and Atlantic Oceans. Canarian Bulwer's petrels visit land colonies for nesting from April to September and nest mainly in small crevices, caves, and holes under rocks, usually close to the sea (Hernández et al. 1990). The Cory's shearwater is the largest (700-800 g) and most abundant procellariiform species in the Canary Islands (Lorenzo 2007). It is well distributed under 1,000 m a.s.l. and it is well known tht it can compete for nests with Bulwer's petrel (Ramos et al. 1997; Bried and Bourgeois 2005).

In the Canaries, the rock pigeon is abundant and well distributed in rural and urban environments, but especially in coastal sectors (Lorenzo 2007). This sedentary and medium sized bird (230-370 g) uses holes and crevices on sea cliffs and marine rocks as roosting and breeding sites (Lorenzo 2007). Nowadays in Tenerife, most rock pigeons seen in the wild resemble birds of domestic origin (*pers. obs.*). Studies conducted on Tenerife indicate feral pigeons are vectors of parasites to native species (Foronda et al. 2004; Abreu-Acosta et al. 2009).

Two species of rats (*Rattus rattus* and *R. norvegicus*) and the feral cat *Felis catus* have been introduced in Tenerife. Rats and cats are abundant on the main island, but they are absent on the marine rocks (Nogales et al. 2006; *pers. obs.*). Introduced mammals intensively predate upon eggs, chicks or adults, which lead to seabirds population declines worldwide (Spatz et al. 2017).

Nesting density, nest characteristics and breeding performance

During the 2017-2020 breeding seasons (June-early September), we visited all known Bulwer's petrel nesting sites (Hernández et al. 1990; Lorenzo 2007). Other potential sites judged for holding colonies (apparently free of introduced predators and with suitable holes) were also visited. We visited 43 sites, spending a total of 218 hours/observer of effective prospection (Fig. S1; Table S1). During daylight hours, we counted the number of Bulwer's petrel and Cory's shearwater nests in places passable by foot using a hand-held flashlight to inspect holes and crevices. We also recorded the presence or absence of feral pigeons, rats, and feral cats according to field cues (individuals, feathers, nests, prey remains, or droppings). Studied sites, including those without petrels, were mapped using aerial photographs, maps, and a GIS (*Qgis* v3.14.16). Four inaccessible sites were inspected using a thermal monocular Pulsar Helion XP50 from vantage points (80-130 m) to estimate the number of nests according to attendance behaviour of adults. Bulwer's petrel and feral pigeon nests from five petrel colonies were described with nine variables (Table 1).

We assess breeding success in 205 breeding attempts (2018, n = 70; 2019, n = 70; 2020, n = 65) in five colonies, four of them located on marine rocks (without introduced predators) and one on a coastal cliff (Fig. S1). Each nest was visited at least twice: to confirm incubation in late June or early July and to record the presence or absence of a full-grown chick in late August or early September. We assumed that nestlings observed during the second visit would fledge successfully.

To identify causes of breeding failure, the nest and its surroundings were inspected, paying special attention to the presence of infertile eggs, eggshells, dead chicks, droppings, and signs of introduced predators. Pigeon nests on nest-sites (crevices, caves, holes, or burrows) previously used by petrels, i.e. in the previous breeding season or early on the same breeding season, were considered breeding failures.

Data analysis

To assess the role of the presence of predators (cats and rats) or nest competitors (pigeons and Cory's shearwaters) on the density of Bulwer's petrel nests, we ran negative binomial Generalized Linear Models (GLMs) with log link functions. Given our limited sample size (43 sites), we compared GLMs including just a single predictor. Then, we ranked the models according to its AICc value (the lowest AICc, the better the model), including a null model containing just the intercept.

To test for potential differences in breeding success (0 = failure; 1 = success) among colonies and years, we ran Generalised Linear Mixed Models (GLMMs) with family binomial (link = logit). We included nest ID as a random factor, given that the same nests were studied each breeding season, and year and colony as predictors. We ranked competitive models according to AICc. To assess potential relationships between breeding success (0 = failure; 1 = success) and nest features, we ran GLMMs with family binomial (link = logit). We included nest ID as a random factor and seven variables describing nests (height, width, depth, chamber height, vertical difference height, curved, and slope) as predictors. We ran all competing GLMMs including just a single factor or variable, as well as the null model including just the intercept, to rank them according to the AICc value.

To test for potential differences of the nest sites of petrels and pigeons, we ran permutations tests and plotted the data on the seven continuous variables of Table 1. In addition, we ran a Principal Component Analysis (PCA) to assess the nesting niche. We used ANOVA permuted tests to compare potential differences in Bulwer's petrel and pigeon nests.

Statistical analyses were run in *R* (v4.0.4). Models were run using the *glm.nb* and *glmer* functions of the *MASS* and *lme4* packages. Models were compared to null models using the *AICc* function (*MuMIn* package) and assumptions were checked using diagnostic plots. We used the package *coin* to conduct the permutation tests.

Results

Distribution and nest density

Most nests (86%) were on marine rocks of the north coast of the island, reaching there the highest nest density (Table S1; Fig. 1). Nest density was higher in colonies without predators like cats or rats, but it was not related to nest competitors such as feral pigeons or Cory's shearwaters (Fig. 2). GLMs indicated that the presence of cats and rats, and habitat location (mainland island *vs*. marine rocks) were the best predictors of nest density (Table 2).

Breeding success and causes of breeding failure

Breeding success varied among colonies and years (Table 2 and Table S2). According to the AICc values of the competitive models, the model containing colony and year as predictors obtained the lowest AICc value (Table 2). The colony located on the main island got the lowest breeding success. No chicks fledged in 2019 and 2020 breeding seasons (Table S2). According to the GLMMs explaining the breeding success in relation to nest characteristics, any of our studied nest variables were related to breeding success. The null model obtained the lowest AICc value (Table 2).

Breeding failure is hard to determine. Thus, the cause of breeding failure in most breeding attempts was unknown (75.0%). At least seven breeding attempts (7.3%) failed due to competition of feral pigeons for nest cavities. Breeding failure by pigeon competition was confirmed in three colonies on marine rocks (Garachico and both of San Juan de La Rambla). At least 6.3% of the breeding attempts failed due to rat predation, all of them located on Los Pedrones on the main island, although most of failed breeding attempts may be caused by predation (Table 3).

Bulwer's petrel and feral pigeon nest characteristics

The Principal Component Analysis plot displayed a considerable overlap among Bulwer's petrel and pigeon nests (Fig. 3). Five out of the seven variables describing nests used by petrels and pigeons reached significant differences. Petrel nests show smaller entrances (lower height and width) and nesting chambers (height). Petrel nest entrances are more tortuous (curved entrance) than those of pigeon nests, and slopes are deeper in pigeon nests. Depth and vertical difference in height between entrance and nest chambers were similar in the two species nests (Table S3, Fig. S2).

Discussion

Our results indicate that the main factor shaping breeding distribution of small procellariiforms is the presence of invasive mammals (Spatz et al. 2014, 2017). Rats and cats have been present in the Canary Islands for several centuries (Nogales et al. 2006). So, these predators have shaped the current breeding distribution of Bulwer's petrel, relegating them to isolated predator-free marine rocks with dense colonies (Hernández et al. 1990). In predator-free sites, such as the Desertas Islands, Madeira, breeding success ranges between 60–75% (Nunes and Vicente 1998), but in invaded colonies on the Bonin Islands, Japan, massive die-off of breeding adults by predation could occur (Kawakami et al. 2010). As a whole, breeding success in Tenerife is low (54.1% of laid eggs produced a fledgling), but a strong spatiotemporal variation was observed. No fledglings were produced during two consecutive seasons on a coastal locality on the main island (#14 in Table S1) where invasive rats occur at high density. By contrast, in the predator-free sites more than 50% of the breeding attempts produced a fledgling (Table S2).

Nest competition with feral pigeons was the main identified cause of breeding failure of Bulwer's petrel, adding an overlooked impact of this pest or invasive species (depending on the native or introduced distribution range) on small seabirds. A minimum of 7.3% of the Bulwer's petrel breeding attempts failed due to interactions with pigeons. In those cases, we confirmed that pigeons occupied petrel nests causing breeding failure (unattended egg or dead chick) or impeding the petrel's use of the nest sites. Similar to small petrels, feral pigeons also benefit from nesting and roosting on predator-free marine rocks to avoid predation. Other agonistic interactions may occur between nesting or roosting pigeons and breeding petrels. Aggressive interactions could disrupt petrel nest attendance and transmit pathogens and diseases, leading finally to petrel breeding failure.

Although we failed to detect a clear relationship between petrel nest density and pigeon competition, systematic breeding failure by pigeon competition could affect nesting density up to local extinction. Field observations support this reasoning. First, the highest nesting density of petrels was recorded in the small rock of La Coronela (#25 in Table S1), where no feral pigeons are present at all. Second, on Roque La Playa (#33 in Table S1), we found only six petrel nests in the same area where a minimum of 18 nests were counted in August-September 1983 (E. Hernández, *com. pers.*). Furthermore, we confirmed the presence of seven pigeon nests, three of them exactly on the same sites previously used by petrels (E. Hernández, *com. pers.*). Third, we could not detect petrels on two predator-free rocks presenting a large extension of apparent suitable nesting habitat (#30 and #31 in Table S1). These rocks hold at least four Cory's shearwater breeding pairs and a large number of breeding and roosting pigeons (> 110 pigeons counted at dusk). Unfortunately, no previous estimates of petrel abundance are available for these rocks. A plausible explanation for the absence of petrels is the interspecific competition with pigeons. In this sense, rough comparisons of old and current photographs show important vegetation damage during the last decades. The *Euphorbia canariensis* population has passed from nine large individuals to only one small individual (Fig. S3), which is probably related to the acidity and accumulation of pigeon excretment (Spennemann and Watson 2017).

As far as we know our results constitute the first evidence of competition for nest sites between feral pigeons and seabirds. Pigeon populations increase primarily around human modified areas (livestock farms, cereal silos, garbage dumps, dunghills, and urban centres). Therefore, petrel breeding colonies closer to these sites are more susceptible to pigeon nest competition. At a global scale, the breeding distribution of Bulwer's petrels, but also other endangered small petrel species, greatly overlaps with the range of native and introduced pigeons. Therefore, nest competition between them may occur, particularly in proximity to human-transformed landscapes. More studies are required to clarify the role of pigeons on petrel nest density, transmission of diseases and pathogens to petrels, and vegetation changes at colonies.

Conservation remarks

The Canarian Bulwer's petrel faces several human-related threats on land, i.e. predation by introduced mammal predators (Hernández et al. 1990), collisions with electric wires (Gómez-Catasús et al. 2021), road casualties (Tejera et al. 2018), habitat destruction and attraction to artificial night lights (Rodríguez et al. 2012). These threats mainly occur on the main inhabited islands. Owing to this fact, the bulk of the breeding pairs are currently restricted to geographically small secure breeding sites (mostly marine rocks). We highlight an overlooked threat to these petrel sanctuaries: pigeon competition for nesting sites. To immediately minimise such interspecific competition, artificial nest boxes should be installed in the main petrel sanctuaries (marine rocks) with high densities of pigeons. Artificial nests must be designed to exclude pigeons and larger procellariiforms, i.e. the Cory's shearwater. This action would facilitate long-term monitoring of population and breeding success, and would help to improve the conservation status of Bulwer's petrel by providing secure nest sites. This action has successfully increased the annual productivity of endangered petrel species (Bolton et al. 2004). Given that rock pigeons can easily become a pest, we also propose the development of culling campaigns in some areas to avoid unnatural densities (Giunchi et al. 2012). Of course, other small petrels (e.g. *Puffinus baroli* and *Hydrobates castro*) and endemic species (i.e. land snails, lizards and plants) living in those marine rocks will also benefit from feral pigeon removal or control. On the main island colonies, control of invasive mammals is urgently required, but additional actions to reduce artificial light attraction, and wire and vehicle collisions should be also considered.

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Tables

Table 1. Variables used to describe nests of Bulwer's petrel *Bulweria bulwerii* and feral pigeon *Columba livia* on Tenerife, Canary Islands.

Variable	Description
Nest type	Proportion of nest cavity sides bounded by rock: all rock, rock crevice; soil bed, soil crevice; and all soil, burrow (1).
Height	Minimum height of the nest entrance (cm).
Wide	Minimum wide of the nest entrance (cm).
Depth	Maximum length from entrance to the nesting chamber (cm).
Nesting chamber height	Height at the nesting chamber (cm).
Vertical difference height	Difference in height from the entrance and the nesting chamber (cm).
Curved entrance	In degrees (0-90º).
Slope	In degrees (0-180º), angle measured in a 1 m radii from the nest entrance considering vertical up as 0º.
Nest material	Absent (0), Present (1).

Table 2. Results of the GLMs and GLMMs explaining nest density and breeding success. See main text for details.

Predictor	df	AICc
Nest density		
Presence of *Felis catus*	3	156.28
Presence of *Rattus* sp.	3	165.63
Habitat (island or rock)	3	166.63
Null model	2	172.52
Abundance of *Calonectris borealis*	3	174.73
Presence of *Columba livia*	3	174.73
Breeding success vs colony and year		
Colony * Year	16	279.33
Colony + Year	8	280.98
Colony	6	281.81
Null model	2	285.46
Year	4	285.74
Breeding success vs nest traits		
Null model	2	285.46
Vertical difference of height	3	286.21
Nesting chamber height	3	286.87
Slope	3	287.07
Curved entrance	3	287.19
Height	3	287.43
Width	3	287.51
Depth	3	287.51

Table 3. Causes of breeding failure of Bulwer's petrel *Bulweria bulwerii* breeding attempts on Tenerife, Canary Islands, during 2018-2020 breeding seasons.

Causes of breeding failure (*n* = 96)	*n* (%)
Unknown	72 (75.0)
Competition with *Columba livia*	7 (7.3)
Predation by rats	6 (6.3)
Abandoned egg	4 (4.2)
Dead chick	4 (4.2)
Broken egg	2 (2.1)
Chick fall from nest	1 (1.0)

Declarations

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Data availability: All data are included in the article and its supplementary information files.

Authors' contributions: BR and AR designed the study. BR, FS, JMM, ES, and AR collected field data. AR analysed the data. YA managed and coordinated the research project. BR and AR drafted the manuscript and all authors commented and approved the final version of the manuscript.

Ethics approval: All procedures in this study were approved by insular and regional governments. Permits to conduct fieldwork were granted by Cabildo de Tenerife (permit numbers: AFF82/17, AFF94/18, and AFF142/19) and Gobierno de Canarias (permit numbers: 2017/10464 and 2018/6842).

Figures

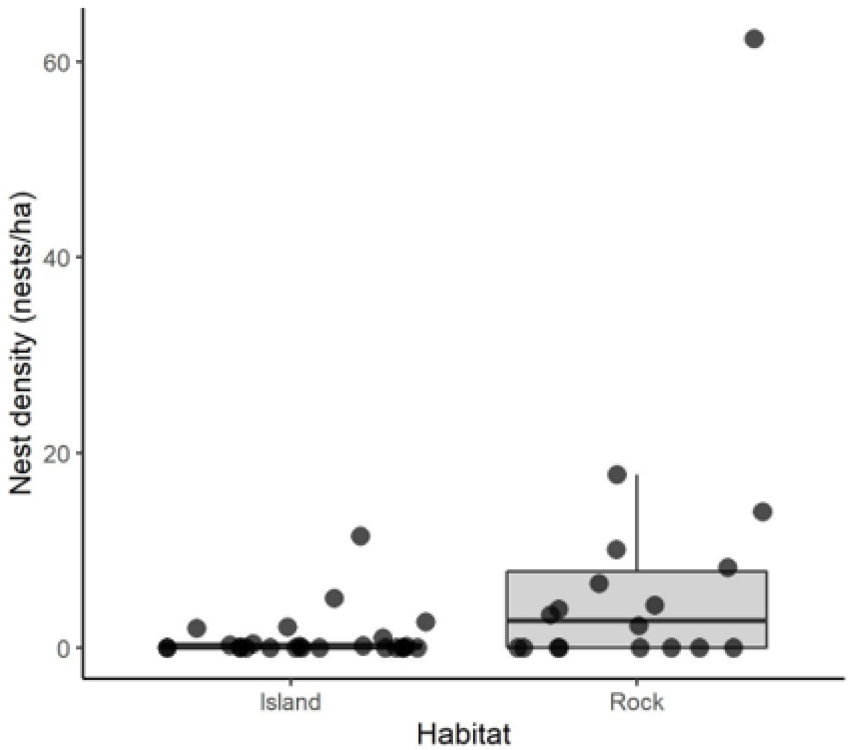

Figure 1

Box plots and data distribution of the Bulwer's petrel nest density on the main island (Island) and on marine rocks (Rock) on Tenerife, Canary Islands. Data have been jittered for a better visualization.

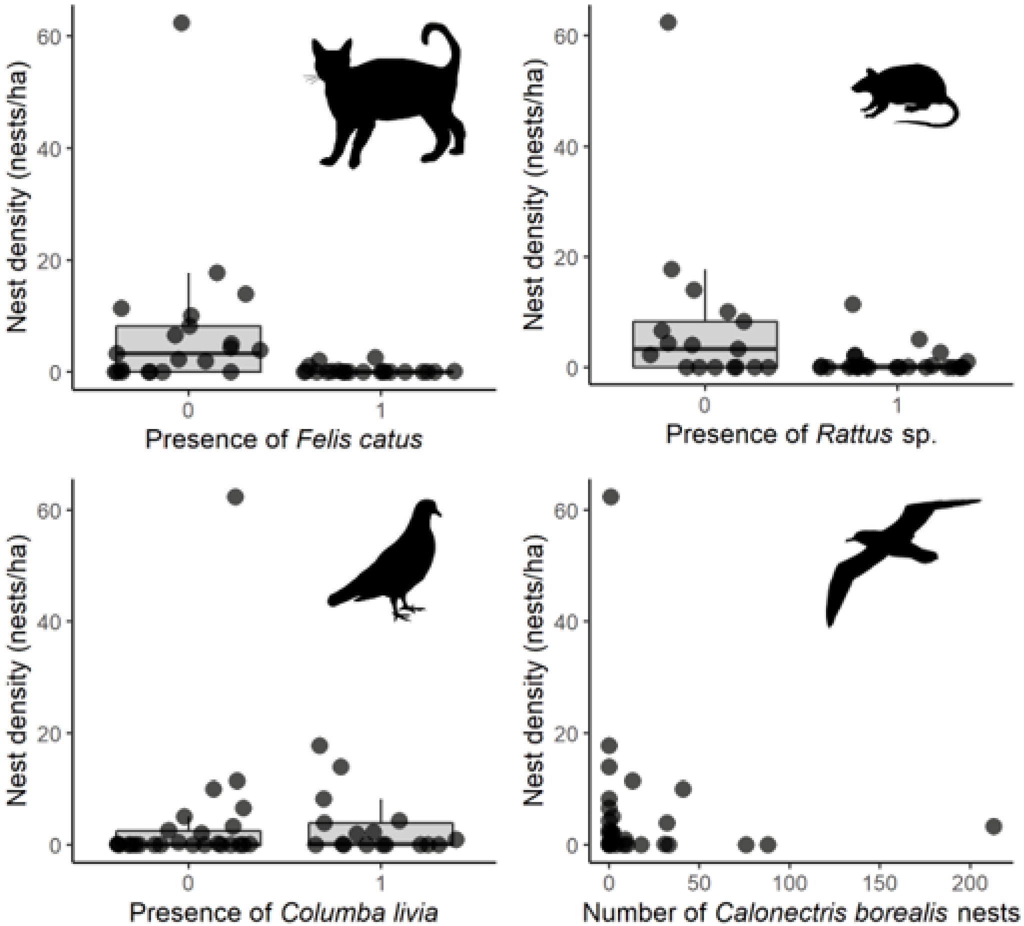

Figure 2

Box plots and data distribution of the Bulwer's petrel nest density according to the presence of introduced predators (cats Felis catus and rats Rattus sp.) and competitors (feral pigeons and Cory's shearwaters Calonectris borealis) on Tenerife, Canary Islands. 0 and 1 indicate the absence or presence of predators or competitors. Data have been jittered for a better visualization.

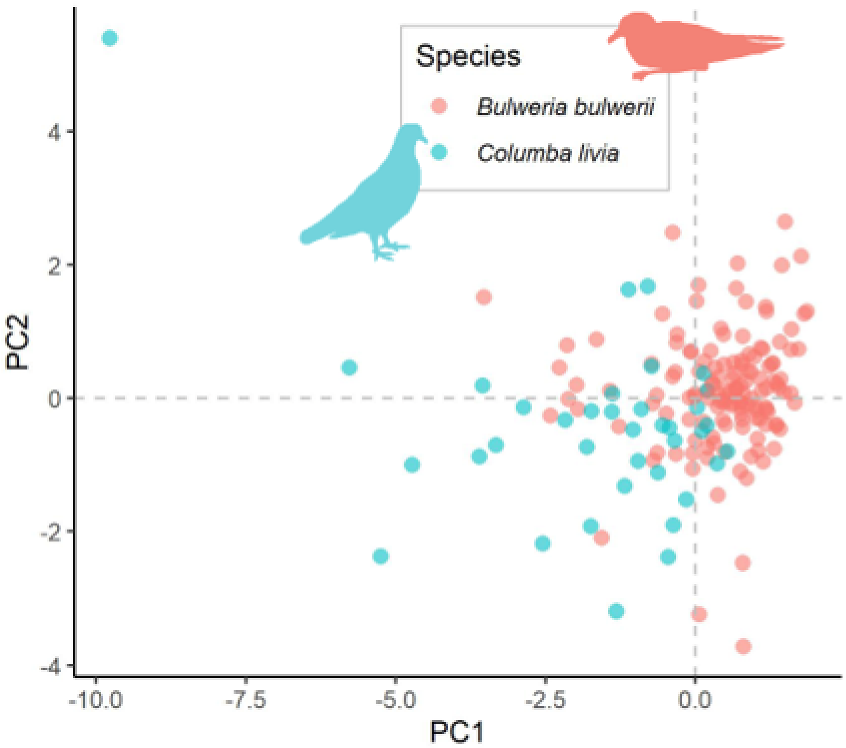

Figure 3

PCA plot of Bulwer’s petrel Bulweria bulwerii and feral pigeon Columba livia nests on Tenerife, Canary Islands.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryMaterial.docx