Habitat categorisation and mapping of a seabird reserve: Ilhéu da Praia, Azores

Sarah E. Long[1*], Jack J. Devlin[2,3], Pedro Raposo[4], Ben J. Porter[1] and Hannah F. R. Hereward[2]

* Correspondence author. Email: sarahlong@protonmail.com
[1] Independent researcher
[2] School of Biosciences, Cardiff University, Cardiff, Wales, UK;
[3] University of Kentucky, Lexington, Kentucky, USA;
[4] Graciosa Natural Park, Graciosa Island, Azores, Portugal.

Abstract
The removal of invasive species and mitigation of habitat loss are vital conservation tools for species such as seabirds. We surveyed habitats across the entirety of a small seabird islet reserve, Ilhéu da Praia, in the Azores, two decades on from mammalian eradication and floral restoration. Here, we present a fine-scale map, to a 12 metre resolution, representing the first full habitat survey of this islet. This resource can serve as a baseline for monitoring future habitat changes to this internationally important seabird islet. Following restoration efforts in the 1990s, the islet's dominant habitats are meadow, grassland dominated by *Festuca petraea,* or a combination of the two. We also report a novel observation of both Band-rumped *Hydrobates castro* and Monteiro's *H. monteiroi* Storm Petrels breeding in the cavities of *Tamarix africana*, an invasive tree species.

Introduction
Islands provide a crucial resource for rare and endangered taxa. Islands are particularly important to species such as seabirds, which require undisturbed land for nesting and have historically used islands as refuges, with fewer predators, competitors, and anthropogenic activities compared to mainland sites (Bellingham *et al*. 2010). In the Anthropocene, however, colonies of seabirds on islands have become increasingly threatened, primarily driven by invasive species, e.g. mammals, particularly rodents (Harper & Bunbury 2015; Brooke *et al*. 2017; Jones *et al*. 2019), and habitat loss, e.g. erosion and overgrazing (Monteiro *et al*. 1996; Cadiou *et al*. 2009; Gizicki *et al*. 2018; Dias *et al*. 2019). Ground- and burrow-nesting seabirds that use such islands are highly vulnerable to invasive species and habitat degradation, which is amplified by their low fecundity (Ratcliffe *et al*. 2009). Additional anthropogenic threats have also emerged for pelagic species such as seabirds: mainly climate change, overexploitation of fishing resources, entanglement in discarded fishing gear, and plastic ingestion (Bertrand *et al*. 2012; Grémillet *et al*. 2016; Savoca *et al*. 2016; Donnelly-Greenan *et al*. 2019). Procellariiformes are one of the most threatened groups of seabirds, their decline driven by many of these threats (Dias *et al*. 2019; Solothurnmann 2019). The removal of invasive species and habitat restoration at crucial breeding sites are valuable conservation tools for seabirds, leading to increased nesting success and enhanced adult survival (Cadiou *et al*. 2009; Brooke *et al*. 2017).

Sooty Tern egg,
Ilhéu da Praia.
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The Azores is an archipelago of islands within the mid-Atlantic Ocean. While all nine main islands of the Azores have been deeply transformed by almost six centuries of continued human presence, it is still possible to find many endemic species (> 70 species of vascular plants, > 260 species of arthropods, and two species of birds (Borges *et al*. 2010; Rodrigues *et al*. 2010; Silva *et al*. 2010)). It is the islets (smaller islands) of the Azores, however, which are particularly important, as their remote nature has enabled them to host unique ecosystems, particularly due to the absence of herbivorous grazers, which deplete and erode the vegetation and soil that many species depend on for food or shelter (Boersma *et al*. 2002). One such example is Ilhéu da Praia (39°3'N 27°57'W, hereafter 'Praia'), a volcanic islet located 1 km east of Graciosa Island, classified in 2007 as a Biosphere Reserve, due to its importance as a breeding site for seabird species such as the endemic Monteiro's Storm Petrel *Hydrobates monteiroi* (UNESCO 2007).

Until the late twentieth century, Praia was used by local farming communities of neighbouring Graciosa as pasture for grazing domestic Goats *Capra argagrus hircus*. Praia was also used as a recreational area by Graciosa residents, mostly during the summer months. Consequently, the disturbance level was too high for many seabirds to breed, particularly terns. Grazing by mammals, including European Rabbits *Oryctolagus cuniculus* hereafter 'Rabbits', (introduced pre-1830s (Andrade 1831)), contributed to continued habitat loss and soil erosion. By 1995, the vegetation over most of Praia was highly degraded, primarily through overgrazing and trampling by domesticated animals and humans, leading to soil compaction and vegetation suppression (Boersma *et al*. 2002; Bried *et al*. 2009). However, due to its proximity to rich marine feeding grounds, absence of mammalian predators, and breeding colonies of several IUCN Red-listed seabirds, Praia is arguably an internationally important site for seabird conservation (Monteiro *et al*. 1996; BirdLife International 2018). Recognising the existing damage, and ongoing threats to this important seabird nesting community, access was restricted and significant restoration work was carried out on Praia between 1996 and 2004: Rabbits were successfully eradicated, soil erosion mitigation measures implemented, much non-native flora removed, and native flora reintroduced (Figure 1) (Bried *et al*. 2009). Invasive Hottentot Fig *Carpobrotus edulis*, which is native to South Africa and forms vast 'mats' to the exclusion of all other plants, was removed, along with Wild Sage *Lantana camara*, which chemically prevents other plants growing adjacent (Taylor *et al*. 2012; Smyth *et al*. 2013). Between 2000 and 2003, various native plants were translocated onto Praia. These included: four *Azorina vidalii*, 450 *Festuca petraea*, 165 *Carex hochstetteriana,* 120 *Tolpis succulenta,* 42 *Erica azorica,* and 32 *Morella faya* (Bried *et al*. 2009). In addition, Graciosa Natural Park frequently controls the non-native tree, *Tamarix africana*.

Alongside the vegetation restoration work, 50 artificial nest boxes were also installed in 1996 to increase suitable breeding areas for terns along the western coast of Praia, the area most deprived of vegetation (Bried *et al*. 2009). The terns on Praia are not observed to use these boxes, unlike in the UK (Morrison & Gurney 2004). In 2000–01, 150 plastic cavity nesting boxes were installed for storm petrels, mostly along the eastern and northern coasts, which have been successfully used (Bolton *et al*. 2004).

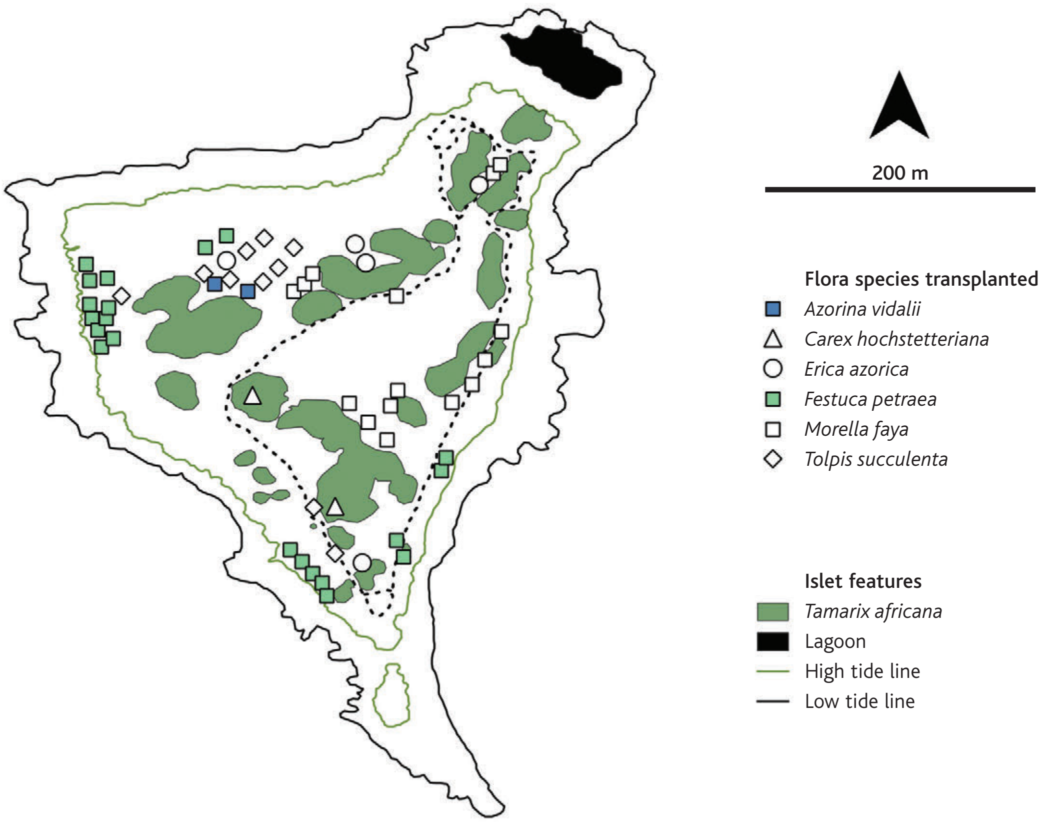

Figure 1. Native plants reintroduced to Praia between 1998 and 2004. Modified from Bried *et al*. (2009), with permission from authors. Reprinted by courtesy of the University of Wisconsin Press. Produced using QGIS version 3.10 (QGIS Development Team, 2019).

Through these conservation approaches of both habitat restoration and nest box installation, there was a rapid increase in breeding seabird numbers and diversity, which now total eight species. Despite not inhabiting the nest boxes, habitat restoration measures led to an increase in Common Tern *Sterna hirundo* and Roseate Tern *S. dougallii*, with populations increasing by 200 and 570 breeding pairs respectively by 2015 (Bried *et al*. 2009; Neves *et al*. 2016). In 2013, Band-rumped Storm Petrel *H. castro* active nests totalled 101, signifying a four-fold increase in breeding attempts from 2000. Similarly, 95 active nests of the endemic Monteiro's Storm Petrel represented a six-fold increase in breeding attempts over the same period. For both storm petrel species, recorded successful breeding attempts in natural nests were in natural crevices in bare rock, and burrows in the ground (Bolton *et al*. 2004). Barolo Shearwaters *Puffinus baroli* now breed on Praia, with over nine attempts in 2013 (Bried & Neves 2015). Cory's Shearwater *Calonectris borealis* breeding pairs number between 120 and 150, although breeding success has not been monitored closely (Bried & Neves 2015). Other birds have been recorded breeding in a variety of the reintroduced flora: Roseate Terns breed in the shelter of the larger *A. vidalii* plants, with chicks observed sheltering under *F. petraea* (Bried & Neves 2015).

Following the conservation measures described above, the flora of Praia has now had approximately 20 years to establish and recover from anthropogenic pressures (Figure 2).

In this study, we surveyed the entire islet and characterised vegetation complexes in 12 x 12 m resolution cells to create the most complete, accurate, and up-to-date vegetation map of Praia. We discuss the conservation implications of these modifications in floral communities, particularly for the recovering seabird communities present. Finally, we present potential uses for this resource as a conservation tool.

Figure 2. A comparison between the vegetation levels on Praia in 1997 from the south, before European Rabbit *Oryctolagus cuniculus* eradication (top) (© Elizabeth Bell / Wildlife Management International Ltd.), and in 2020 (bottom) (© Ben Porter).

Methods

Study site

Praia is a small 0.1 km² islet, with an elevation summit of 52 m. Praia has a relatively stable climate, with a year-round average temperature range of 13°C to 22°C, and with substantially more rainfall in the winter months (October–February). The annual mean rainfall is 1,076 mm (Climate-data.en 2020).

Habitat categorisation

There are 197 flora species that are considered native to the Azores, of which at least 15 are found on Praia (Schaefer 2005; Silva *et al*. 2010). Identification of plants and habitat complexes was achieved using visual identification and subsequently identified to species level using multiple sources (Schaefer 2005; CABI 2020; Kew Science 2020; Sociedade Portuguesa de Botânica 2020). We assigned habitat categorisations based on the dominant plant species/substrate type present, with the exception of the 'meadow complex' habitat, in which three species were found to be present in varying proportions with none being particularly dominant (Table 1).

Table 1. Dominant habitat types present on Praia. * native flora species; ** endemic Azorean species.

Habitat Type	Status
*Azorina vidalii***	Four plants reintroduced 1998 (Bried *et al.* 2009).
Artificial	The structure (now a small research base) was built pre-1900s.
Bare volcanic rock	Naturally occurring. Susceptible to erosion.
Bare soil	Naturally occurring. Susceptible to erosion.
Volcanic boulders	Naturally occurring. Susceptible to erosion.
*Festuca petraea***	450 plants reintroduced 2000–03 (Bried *et al.* 2009).
Meadow complex	Mixed species habitat, composed primarily of: *Daucus carota azoricus***, *Plantago coronopus, Plantago lanceolata**
Tamarix africana (Deciduous tree)	Estimated arrival date to the Azores in the fifteenth century (Costa *et al*. 2013). Possible arrival date to Praia in the early twentieth century.

Other flora species found in low densities on Praia, but not at densities high enough to constitute or exclusively apply to a specific habitat type, included: *Anagallis arvensis** (Primulaceae), *Apium graveolens** (Apiaceae), *Asplenium marinum** (Aspleniaceae), *Atriplex prostrata** (Amaranthaceae), *C. hochstetteriana*** (Cyperaceae), *Cyperus esculentus* (Cyperaceae), *Erica azorica*** (Ericaceae), *Euphorbia azorica*** (Euphorbiaceae), *M. faya** (Myricaceae), *Picris echioides*, (Asteraceae), *Solidago azorica*** (Asteraceae), *Spergularia azorica*** (Caryophyllaceae), *T. succulenta** (Asteraceae). In line with Table 1, asterisk (*) denotes native species, whereas (**) denotes species endemic to the Azores. Unmarked species are non-native.

Habitat survey

We surveyed the habitat of Praia between October and December 2019. Using a handheld Garmin eTrex 20x GPS, points were identified every 0.5 arc seconds (approximately 12 m, or 1/3,600 of a degree) after allowing sufficient time for the GPS to stabilise. At each point, the dominant habitat category (> 50% of habitat) in a 5 x 5 m square cell around the central point was defined and recorded. Where two habitats were present and neither dominant, both habitat types were logged as a mixed habitat e.g. 'bare rock'/'meadow complex'. All accessible points were assessed in this manner, whilst non-accessible points, such as hazardous/tidal and thickly vegetated areas (i.e. centre of *Tamarisk* trees), were assessed by sight (either by eye or with binoculars) from the nearest accessible point. To minimise observer error (see review by Morrison 2016), all data points were made by the same primary surveyor, accompanied by at least one field assistant. Specific plant identifications were discussed by multiple people to minimise overlooking and misidentification errors.

Digitisation of mapping data

Habitat mapping data were transferred into QGIS version 3.10 (QGIS Development Team, 2019) using the EPSG:4326 - WGS 84 coordinate system. Our sampling points were created at 5 x 5 m and assigned a unique colour scheme and pattern, according to their habitat categorisation. We created a regular grid of 12 x 12 m cells (i.e. approximately 0.5 arc seconds) at 50% opacity across the islet and assigned each grid cell a unique colour scheme and pattern, according to the habitat categorisation of its central 5 x 5 m sampling unit.

Seabird observations

Ad hoc observations of habitat use by breeding storm petrels took place between October and December 2019, and were made in conjunction with a larger project (spanning March 2019–March 2020), which included breeding population monitoring of the two species of storm petrel in both artificial and natural nests.

Results

Habitat survey

We defined eight distinct habitat categories and 15 mixed habitat categories across the 455 cells surveyed (Figure 3). Of these, five habitats dominated the islet landscape: 'meadow complex' (N = 84; 18.5%), '*F. petraea*' (N = 62; 13.6%), 'bare volcanic rock' (N = 56; 12.3%), '*T. africana*' (N = 56; 12.3%), and 'volcanic boulders' (N = 47; 10.3%). 'Meadow complex' habitat was mainly found in the central and eastern regions of Praia, whereas '*F. petraea*' was distributed in the western and southern extents of Praia, mainly at lower altitudes. '*T. africana*' was mainly found alongside the meadow habitat, with 'bare volcanic rock' and 'volcanic boulder' habitats found around the periphery of Praia (Figure 3). The most numerous mixed habitat was '*F. petraea*'/'meadow complex' (N = 34; 7.5%), followed by 'meadow complex'/'*T. africana*' (N = 22; 4.8%), 'bare soil'/'*F. petraea*' (N = 14; 3.1%), 'bare volcanic rock'/'meadow complex' (N = 11; 2.4%), and '*A. vidalii*'/'*F. petraea*' (N = 9; 2.0%). The least numerous distinct habitat type was 'artificial' (N = 1; 0.2%).

Over the last 20 years since the native plants were reintroduced (Figure 1), *A. vidalii* has expanded over much of the northwestern area of Praia and is now the dominant or co-dominant habitat type in 7% of the grid cells surveyed (Figures 1 and 3). Praia's meadow of *A. vidalii* is now one of the largest fields of the monospecific genus *Azorina* in the Azores. Similarly, *F. petraea* has now established over much of the lower altitudinal areas of Praia (Figures 2 and 3), on land that was previously overgrazed (Figures 1 and 2). *F. petraea* is now the dominant vegetation type in 13.6% of the grid cells surveyed and is co-dominant in a further 15% of cells, often forming a mixed habitat with bare soil. Conversely, reintroductions of *C. hochstetteriana, T. succulenta, Erica azorica* and *M. faya* (Bried *et al*. 2009) have been less successful, and were not observed in great enough numbers in this study to constitute a distinct habitat type.

Seabird observations

We observed Cory's Shearwaters, as well as Band-rumped and Monteiro's Storm Petrels, successfully breeding in '*F. petraea*', 'bare volcanic rock', and 'meadow

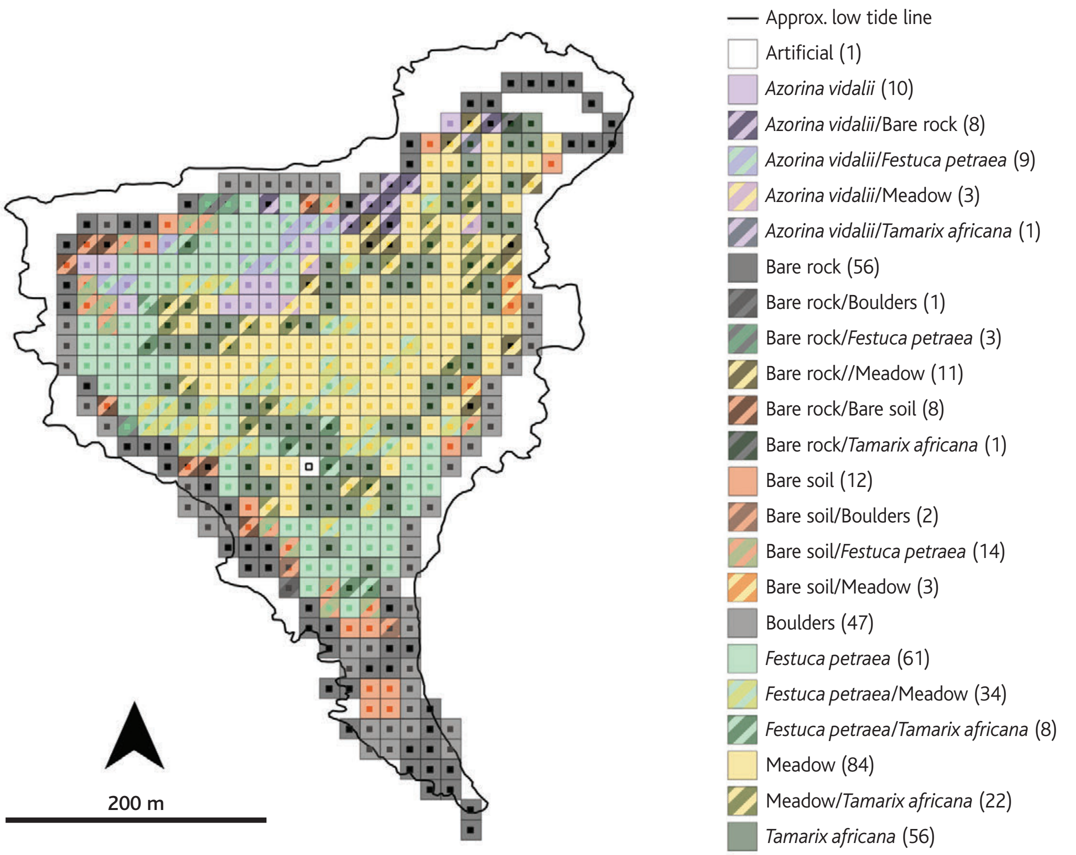

Figure 3. Habitat map of Praia Islet, Azores. Habitat type was defined at 5 x 5 m, forming the central square of each 12 x 12 m cell. Abundances for each habitat type are listed in brackets after the category, representing the number of 5 x 5 m sampling points each was recorded in (total instances = 455). Low tide line sourced from Google Earth (Google Earth 2020). Produced using QGIS version 3.10 (QGIS Development Team 2019).

complex' habitats. In addition, Barolo Shearwaters successfully bred in '*F. petraea*'. Interestingly, these species nesting within *F. petraea* have been observed nesting in cavities within the plant communities themselves, without excavating a burrow, contrasting their behaviour in other habitat types. Additionally, Cory's Shearwaters successfully breed underneath the non-native *T. africana*. Barolo Shearwaters have also been observed excavating nests around the *T. africana* trees, but the breeding success was unknown. Furthermore, Band-rumped Storm Petrels were also observed to successfully breed within the *T. africana* trees, using cavities and natural holes at the base of the trunks. Monteiro's Storm Petrels were also seen prospecting these holes but were not observed breeding.

Discussion

This study presents the first complete, high-resolution habitat map of Praia Islet. We thereby demonstrate how the multi-faceted conservation efforts in the 1990s and early 2000s have transformed the habitat structure and landscape of this important seabird nesting site. In this work, we surveyed habitats across the whole of Praia to a resolution of 5 m cells, 12 m apart. Following conservation and habitat restoration work conducted 20 years ago, from 1996–2004, we have mapped the spread and status of some of the reintroduced, and non-native, flora species. However, a more in-depth assessment to determine the range expansion or contraction of these reintroduced species would be beneficial. Specifically, the *T. succulenta* plants growing on Praia, and found in low numbers in the Azores, may be a new species or subspecies, endemic to the Azores or even to Graciosa (Kerbs *et al*. 2020; Crawford *et al*. 2020). The plants found on Praia may be of considerable conservation importance, due to the threats of anthropogenic habitat degradation and competing exotic plants on inhabited Azorean islands, particularly on Graciosa (Borges Silva *et al*. 2015). A population estimate (i.e. the number of individual plants) on Praia would investigate their success on this protected islet.

Comparing our updated vegetation map with previous work by Bried *et al*. (2009) (Figure 1), it is evident that the habitat restoration on Praia has been highly successful. Whilst differing sampling methodologies prevent direct comparisons between present-day habitat composition and that of two decades earlier (i.e. Bried *et al*. 2009), we observe several patterns. Most evident is the spread of *F. petraea,* which has spread from 450 plants to being present on almost 30% of the islet's surface (Figure 3). This has positive implications for Praia's seabirds, as they were previously constricted to 'bare volcanic rock' habitat, with limited nest burrows in earth banks (Bolton *et al*. 2004; Bried *et al*. 2009). This study has also identified that Procellariiformes now breed successfully throughout four of the five most prevalent habitat categories ('meadow complex', '*F. petraea',* 'bare volcanic rock', '*T. africana',* 'volcanic boulders'). Specifically, *F. petraea* is used as a nesting habitat by both Cory's and Barolo Shearwaters as well as Band-rumped and Monteiro's Storm Petrels, similar to the behaviour of other Procellariiformes (Gillham 1963). For the first time, we describe the nesting of Band-rumped Storm Petrels in the base of the non-native tree, *T. africana*, and the use of this tree cover by Cory's and Barolo Shearwaters. This use of trees as nest sites is similar to observations of nesting Leach's *H. leucorhous* and Fork-tailed Storm Petrels *H. furcatus* (Chilelli 1999; Vermeer *et al*. 1988). Through control efforts by Graciosa Natural Park, there appears to have been little change in *T. africana* distribution between these two time points. It is, however, important to note that left untreated, the trees would likely spread across a far greater extent of the islet. This nesting observation presents difficult conservation decisions between avoiding removing nesting habitat and controlling the spread of the *T. africana* tree cover, which, if allowed to spread, could cause a challenge to seabirds landing and taking off from Praia, particularly newly fledged individuals. The effects of these non-native trees on the breeding success of Procellariiformes on Praia could potentially be investigated in future studies.

This study contributes to a growing body of evidence documenting the effectiveness of invasive species eradication and subsequent habitat restoration as conservation tools for island-nesting seabirds (e.g. Cadiou *et al*. 2009; Brooke *et al*. 2017; Bell *et al*. 2019). Non-native Rabbits are known to be detrimental to the breeding of nesting seabirds, and previous studies have shown the removal of Rabbits to increase breeding success in Procellariiformes (Zino *et al*. 2008). Additionally, anthropogenic activities cause disturbance to seabird colonies and lower breeding success (Anderson & Keith 1980). Having almost fully removed all these pressures to seabird breeding on Praia 20 years ago, seabird population recovery is ongoing. As Praia hosts 40–50% of the world's population of Monteiro's Storm Petrel (Oliveira 2016), classed as 'Vulnerable' by the IUCN (BirdLife International 2018), it is essential that habitat restoration is maintained to support this endemic Azorean species. Whilst other seabird species that breed on this islet are all classified as 'Least Concern' (BirdLife International 2018), protecting the colonies on this site creates an extra buffer to the global populations, increasing resilience against continued climate change and direct anthropogenic activities, e.g. at-sea activities (Dias *et al*. 2019).

The habitat map (Figure 3) produced within this study shows the increase in available breeding areas for seabirds on Praia, which, along with reduction in disturbance, is key to their breeding success. To fully investigate the impacts of habitat restoration, we suggest that a full-islet seabird census needs to occur, to determine the habitat usage of each species, including both terns and Procellariiformes, and quantify the relative importance of each habitat for breeding. Data on breeding bird populations, and their proportional habitat use, do not yet exist. In order to solve this, an infra-red/thermal imaging camera study during the breeding seasons of each species would provide a non-invasive option that would minimise sampling effort and disturbance to any breeding seabirds, whilst enabling specific habitat use to be quantified (Perkins *et al*. 2018). This could then guide further decision-making on habitat management of Praia. The continued monitoring of accessible natural, and all artificial, nests will allow average egg and chick survival rates to be extrapolated across the islet to allow for predictions of breeding success. Our mapping of non-floral habitats, such as 'bare soil' and 'bare volcanic rock', create a baseline to allow for future mapping of erosion, a factor of habitat loss for seabirds in the Azores (Monteiro *et al*. 1996).

Finally, as plant communities and habitat composition on Praia are continually changing, our habitat map and categorisation scheme will also act as a baseline from which future changes can be monitored.

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