

Ecological assessment of an unprotected natural forest area in São Miguel Island (Azores) and its potential conservation value

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Abstract

REGO, R.M.C., SILVA, L.B., PORTEIRO, J., MOURA, M., MEDEIROS, F., RESENDES, R., ROXO, G., BRANCO, N., SILVA, L., 2026. Ecological assessment of an unprotected natural forest area in São Miguel Island (Azores) and its potential conservation value. *Folia Oecologica*, 53 (2): 145-159.

Relevant habitats occurring outside protected areas act as buffers for nearby reserves and provide valuable ecosystem services. In the Azores, 24% of the land is protected, but important biodiversity areas remain outside these boundaries. In this study, we assessed an area adjacent to São Miguel Island Natural Park, classified as natural vegetation. Plant and bird species were listed, 5 × 5 m plots used to characterise the plant communities and indicator species. Dendrometry approaches were used to study the invasive dynamics of *Clethra arborea*. Results exhibited two different plant communities: a *Laurus azorica* forest invaded by *C. arborea*; and a *Calluna vulgaris* scrubland with a rich herbaceous layer. Both communities reflected past human disturbances, possibly linked with collection of top-soil as substrate for pineapple cultivation. The results also confirmed that relevant areas for biodiversity exist outside protected areas in the Azores, and if restored, can potentially support biodiversity conservation.

Keywords

Azores, biodiversity conservation, ecological assessment, *Laurus* forest, protected areas

Introduction

Protected areas are considered a pivotal instrument for the conservation of the world's biodiversity (PULIDO-CHADID et al., 2023), providing habitat for animal and plant species, some of them quite rare (QUEIROZ et al., 2014). The Protected Planet Report updated in 2024, stated that 17.54% of terrestrial and inland water areas, and 8.45% of marine ecosystems are within natural parks and other protected areas, in more than 300,000 established protected areas worldwide (UNEP-WCMC and IUCN, 2024). However, the majority of the world's wild animal and plant species cannot establish themselves and maintain viable populations inside protected areas only, with a considerable part remaining outside protected lim-

its (DUDLEY, 2008). In certain cases, animal species rely in areas located outside protected areas to be able to feed and reproduce, because vital resources exist in insufficient proportions inside protected areas (DEFRIES et al., 2007).

Many endemic species can be found on small remnants of natural habitat, outside protected areas and surrounded by agricultural lands and urban areas, thus reinforcing the need to conserve areas located outside protected limits (COX and UNDERWOOD, 2011). Unprotected adjacent natural areas can enhance landscape connectivity, provide important biodiversity and ecosystem services and support ecological processes (VON STADEN et al., 2022). These areas also work as buffers to conserved areas (SÁNCHEZ-AZOFEIFA et al., 1999) and contribute to the conser-

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vation of species with wide ranges (GÁLVEZ et al., 2013).

Currently, the main global threats to natural areas are climatic changes, land use changes and Invasive Alien Species (IAS) which have a much greater impact in island ecosystems (BELLARD et al., 2017; RUSSELL et al., 2017). IAS can prey or compete directly with endemic and native species for resources and space, which are particularly limited in islands (SILVA et al., 2008). One of the main vectors for biological invasions is land use changes (e.g., agriculture, deforestation), while climate changes forecasts unpredictable impacts when referring to the possible establishment of new IAS's, future distribution, and management (RUSSELL et al., 2017).

Islands are particularly vulnerable to the effects of anthropogenic pressures, with severe ecological consequences (NOGUÉ et al., 2021; REGO et al., 2024). The human settlement on the Azorean islands, by the 15th century, promoted several changes in the islands natural landscape, which profoundly altered the composition and structure of the Azorean natural vegetation (SILVA and SMITH, 2006; COSTA et al., 2013). The former vegetation of the islands was represented by several types of forests (ELIAS et al., 2016). Currently, the natural vegetation communities have been largely reduced and fragmented, consisting of coastal and mountain scrublands, natural meadows (e.g., *Festuca*, etc.), natural forests (Juniper woodland, Laurel forest, etc.), coastal vegetation and the vegetation typically associated to wetlands, such as bogs and lake shores (DIAS, 1996; ELIAS et al., 2016). Large percentages of the territory are occupied with pasturelands (42%), exotic woodlands (30% of forested areas), production forests mostly of *Cryptomeria japonica* D. Don (Taxodiaceae, 20%), remaining a small land portion that is occupied by crop fields, vineyards, orchards, hedges and gardens (SILVA and SMITH, 2006; COSTA et al., 2013). The anthropogenic pressures resulted in the loss of the forests dominated by *Prunus lusitanica* subsp. *azorica* in the Azores (GÓIS-MARQUES et al., 2020), and in the decline of Azorean Laurel forests (FLORENCIO et al., 2021). Moreover, one endemic plant, *Vicia dennesiana* H. C. Watson is extinct (FERNÁNDEZ-PALACIOS et al., 2025), with many other species remaining in danger (SILVA et al., 2009).

The islands also harbour several species of endemic birds (MEDEIROS et al., 2005), being *Pyrrhula murina* (Godman, 1866) the most emblematic bird, whose habitat is restricted to the council of Nordeste, in São Miguel Island. A recent study highlighted that ten bird species, including several single-island endemics, already became extinct in the Azores (FERNÁNDEZ-PALACIOS et al., 2025), whilst the endemic *P. murina* almost became extinct in the XX century, with only as many as 100 birds remaining, by 1980, as a result of human hunting practices and habitat decline (COSTA et al., 2023).

Recently, dendrochronological approaches have expanded in the Azorean archipelago, unlocking the relationships between climate-growth of several endemic trees, such as *Laurus azorica* (Seub.) Franco (Lauraceae; MATOS et al., 2019; PAVÃO et al., 2023a), or the holly, *Ilex azorica* Gand. (Aquifoliaceae; PAVÃO et al., 2023b). Moreover,

these studies are also important for conservation purposes, in the ecological characterisation of natural vegetation areas, to detect anthropogenic impacts and forest regeneration (MATOS et al., 2019) and the invasive dynamics of exotic trees, which can be helpful for its effective management in the natural areas (BORGES SILVA et al., 2017).

With the purpose of protecting Azorean natural habitats, the Regional Network of Protected Areas of the Autonomous Region of Azores was created (DLR n.º 15/2012/A), establishing the Island Natural Parks (CALADO et al., 2009). Additionally, other areas were included under Natura 2000 sites, and in other international agreements, such as Important Bird and Biodiversity Areas (IBA), Ramsar sites and the World Network of Biosphere Reserves of UNESCO. Furthermore, ad hoc legislation was integrated to protected endangered endemic species following the Bern Convention and the Habitats Directive (BRAGAGNOLO et al., 2016). Currently, São Miguel Island Natural Park includes 23 protected areas (AZOREAN GOVERNMENT, 2025), and in 2022, 24.1% of the Azorean territory was classified within the Protected Areas Network and the Natura 2000 (SRAAC, 2024). Despite those efforts, there are still many areas that lack a protection status, and adjacent unprotected sites remain understudied. For example, one third of the natural habitats and vegetation patches in Pico Island remain outside protected areas and are found highly degraded (MOREIRA et al., 2018).

A better evaluation of the potential and importance of these areas for the local biodiversity is required. This work addresses this issue, by testing the hypothesis that natural vegetation areas located outside protected areas are relevant for local biodiversity conservation. We evaluated a natural vegetation area identified in the Azores Forest Inventory, located in Achada das Furnas (São Miguel Island) and presently not protected by any of the networks already mentioned, despite its proximity with nearby Protected Areas. Thus, the goals for this work are: (i) to elaborate a list of the existing vascular plant taxa and avifauna in the study area; (ii) to analyse the importance of endemic, native, naturalized and invasive species; (iii) to estimate the age at breast height of the most representative tree species present, at endemic and invasive levels and try to understand the dynamics of the invasion process and; (iv) to evaluate the importance of the study area towards conservational purposes. The ultimate goal would be to generate data that support the possible inclusion of this natural forest patch in São Miguel Island Natural Park.

Materials and methods

Study area

The Azores archipelago, which is located north of the Atlantic Ocean (between latitudes 37–40°N and longitudes 24–31°W), belongs to the biogeographic region of Macaronesia. The archipelago is composed of nine islands of

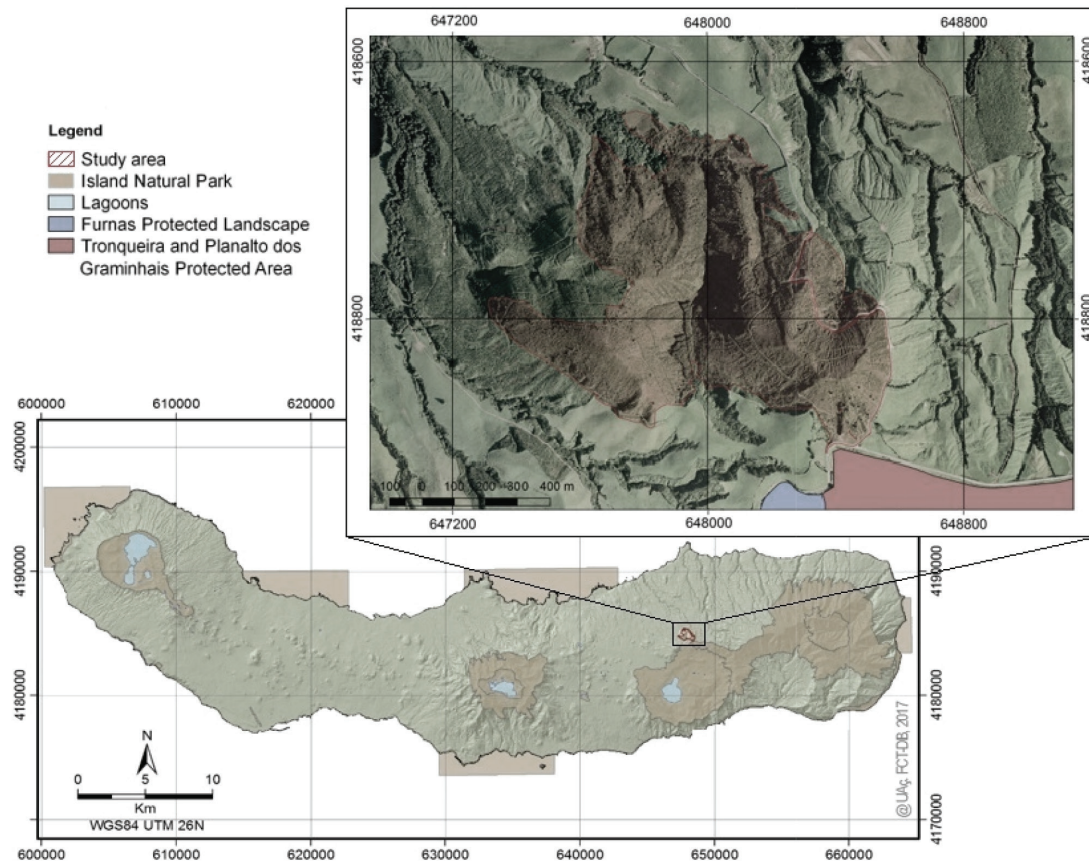


Fig. 1. Location of the study area and of the São Miguel Island Natural Park.

volcanic origin, divided into three groups: eastern (Santa Maria and São Miguel), Central (Terceira, Graciosa, Pico, São Jorge and Faial) and western (Flores and Corvo) (QUEIROZ et al., 2014). This work focuses on a natural vegetation area located in Achada das Furnas (São Miguel Island), between 600 and 750 m asl. The area is adjacent to Tronqueira and Planalto dos Graminhais Protected Area and at 132 m from the border of Furnas Protected Landscape, Fig. 1), with a total of 66.7 ha. Precipitation levels range between 1,400–3,000 mm and the annual mean temperature is of 10–13 °C (AZEVEDO, 1996).

Plot sampling

Field work followed previous studies (QUEIROZ et al., 2014; REGO et al., 2024). Plots of 5 × 5 m were made in several locations inside the study area, based on the accessibility of the habitat. To ensure that the main habitat types remain properly represented, sampling was stratified to include core (plots inside the forest, far from roadsides to avoid edge effects) and margin areas (roadsides and forest edges), as well as scrubland and forest. A GPS (Garmin eTrex) was used to determine the geographical position and altitude of the plot. A total of 25 plots were sampled (20 core and 5 margin plots). All vascular plant species within each plot were identified (SCHÄFER, 2005), and the percent cover was estimated visually, as the vertical projection of the canopies, by dividing the 5 × 5 m plot into four subplots. Whilst we focused on vascular plants,

bryophytes were also recorded when present, particularly *Sphagnum* spp., which were very abundant in some plots.

Birds transects

Line transects of 1 km were done to assess avifauna diversity present in the area. A total of 10 transects were done between the fall of 2016 and the summer of 2017, where every bird species seen or heard was recorded. Transects were done at constant pace (~30 mins.) under suitable climatic conditions (BIBBY et al., 1992). In a paper sheet, the transect name and length, weather conditions, date and hour were recorded. Also, a line representing the transect was drawn, with reference points at each 200 meters, where the exact position of each bird species was recorded, using short names (e.g.: Bb as for *Buteo buteo rothschildi*) (BIBBY et al., 1992).

Tree ring sampling and reading

For tree age determination, a total of 60 samples (increment cores and stem discs) of endemic species (*Laurus azorica* and *Ilex azorica*) and invasive species (*Clethra arborea*), were collected. In average, 20 trees were sampled per species.

For each sampled tree, we measured diameter at breast height, *DBH* (using a diameter measuring tape) and total tree height, *H* (using a Vertex IV 360_ and Transponder T3, Haglöf Sweden AB) (MATOS et al., 2019). Incre-

ment cores and stem discs were sampled at breast height (1.30 m). For the endemic species, increment cores were collected using a Hagl f increment borer, whereas for the invasive species, for those with $DBH < 10$ cm, stem discs were taken and for those with $DBH > 10$ cm, increment cores were collected (BORGES SILVA et al., 2017; MATOS et al., 2019; PAV O et al., 2023a, 2023b).

After collection, samples were allowed to air-dry for 1–2 weeks, depending on the condition of the samples. The stem disc surface and increment cores were sanded to a fine polish using increasingly finer grades of sandpaper (up to grit 600), to increase ring visualization in those samples presenting unclear ring tree boundaries (BORGES SILVA et al., 2017). The number of tree rings was estimated through counting under a stereomicroscope (Leica-Zoom 2,000, Model NO. Z30 V, 240 vac, maximum magnification of 100 \times). Since the samples were only collected at breast height, the age determined will correspond to the tree age at breast height (i.e., lower than total tree age).

Statistical analyses

Microsoft Office Excel was used to calculate the mean number of sightings per transect for each bird species. Then, for the vegetation characterisation, percentages of cover for each of the species counted inside each plot were calculated and also categorised according to their colonisation status (endemic, native, naturalized and invasive). We also calculated species richness (SHANNON, 1948) both in total number of species observed per sample and in percentage, by their colonisation status. Then, the frequency of each species was calculated (%), that is, the number of times it was found inside each plot. Finally, we calculated the importance of each species, based on cover and frequency, through the sum of the two percentages and subsequent division by two, thus obtaining a value that translates the importance of each species in the study area.

On R environment, v. 4.2.3 software (R DEVELOPMENT CORE TEAM, 2025) we have estimated existing distances along the plant communities sampled inside the area, through the application of Bray-Curtis dissimilarity coefficient. We used the species' cover raw data for this analysis, to preserve the relative contribution of dominant species to community dissimilarity. This was coupled with Ward's Minimum Variance Clustering, which is a method capable of forming groups while minimizing the within-group sum of squares, then represented on a dendrogram (BORCARD et al., 2011). To determine the optimal number of clusters, we applied two algorithms: ROUSSEEUW (1987) quality index approach based on the silhouette widths, and according to Mantel statistic (Pearson) (LEGENDRE and LEGENDRE, 2012; REGO et al., 2024). To assess if the dendrogram preserves the pairwise dissimilarities, we calculated Spearman correlation, which correlates the original dissimilarity matrix with the cophenetic matrix derived from the clustering analysis, giving a result between –1 and 1. Values closer to 1 indicate a good representation of the original dissimilarities in the cluster structure (LEGENDRE and LEGENDRE, 2012). To access for differences

in species composition between the clusters defined, we used PERMANOVA, through the function `adonis2()` contained in the `vegan` package (OKSANEN, 2015), based on Bray–Curtis dissimilarities and 999 permutations. We also employed PERMDISP to test the homogeneity of the multivariate dispersion, using the standard 999 permutations (ANDERSON, 2006; OKSANEN, 2015).

For dendrometry, means of DBH , total height and number of rings have been calculated, as well as the maximum number of rings obtained for each species. This was then, represented in a scatter plot with linear regression analyses, to assess what kind of relationship exists between DBH and the number of rings for each species.

Indicator species analysis

To detect possible differences between marginal and core plots, we calculated Indicator species in R v.4.2.3, with the R package "Indicspecies" (DE C CERES et al., 2010), which consists in an improvement of the `IndVal` method by DUFR NE and LEGENDRE (1997). As an abundance metric, species percent cover was used. The `multipatt()` function was used, with 999 permutations, to return a statistic (`IndVal`), and its corresponding significance (p -value < 0.05). To ensure statistical robustness, only the species that occurred in at least 5 plots were considered for this analysis (total of 40 plant species out of 47 taxa).

SWOT analysis

We identified strengths, weaknesses, opportunities, and threats related to a possible inclusion of this area into the S o Miguel Network of Protected Areas, by performing a SWOT analysis. As the Internal factors, we considered Strengths and Weaknesses as those variables more closely related with the environmental conditions of the study area. The Opportunities and Threats (External conditions) were based in the characteristics of the territory and of the surrounding areas, particularly regarding its economic and social settings (SCOLOZZI et al., 2014).

Results

Lists of species

We recorded 45 vascular plants and 14 bird species in the study area. Two bryophytes were accounted: *Polytrichum commune* and *Sphagnum* spp., which was highly abundant in some plots. We also observed the bat, *Nyctalus azoreum* Thomas (Vespertilionidae). The lists of vascular plants, including the bryophytes found, and birds are given in Supplementary Tables 1 and 2, respectively.

Bird richness

The most frequently observed species were *Fringilla moreletti* (Pucheran; 8.1 individuals per transect), *Erithacus rubecula* (Linnaeus; 6.7) and *Sylvia atricapilla atlantis*

Table 1. Mean absolute and relative richness and mean percent cover obtained for each plant status, based on the 25 sampled plots

	Mean richness	Richness (mean %)	Cover (mean %)
Endemic	4.40	30.97	28.08
Native	5.44	37.52	37.44
Naturalized	0.76	5.90	2.39
Invasive	3.64	25.57	32.09

Table 2. List of indicator species associated with two plot types (Core and Marginal), from a total of 47 plant taxa retrieved from 25 plots

Plot type	Taxa	Statistical value	p-value
Core	<i>Laurus azorica</i>	0.81	0.044*
Marginal	<i>Gunnera tinctoria</i>	0.989	0.001***
	<i>Festuca francoi</i>	0.954	0.002**
	<i>Erigeron karwinskianus</i>	0.883	0.001***
	<i>Leycesteria formosa</i>	0.871	0.003**
	<i>Potentilla erecta</i>	0.845	0.019*
	<i>Holcus rigidus</i>	0.784	0.036*
	<i>Hypericum foliosum</i>	0.717	0.037*
	<i>Duchesnia indica</i>	0.632	0.037*

Signif. codes: *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

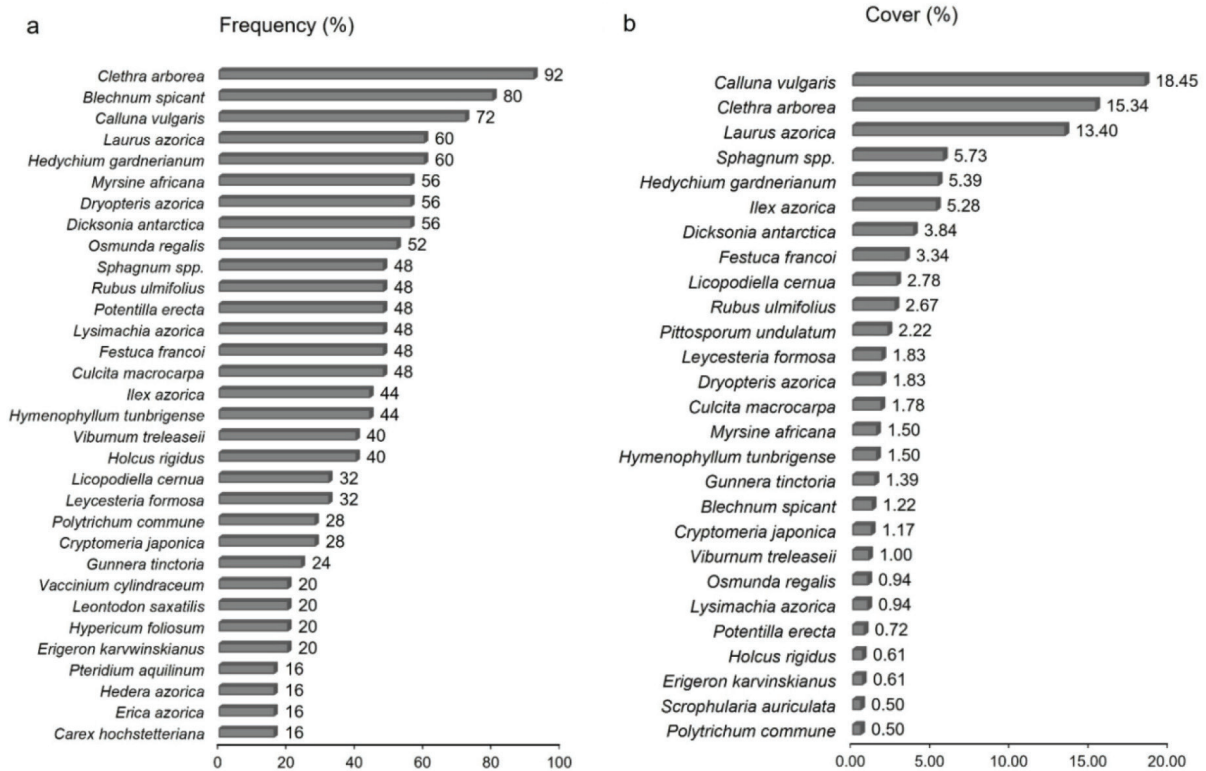


Fig. 2. Frequency (a) and Cover (b) percentages of each individual species inside the study area. For the frequency, were considered only those species that appeared in a minimum of four of the 25 plots done, whereas for cover, only those species with a value above 0.5% were included.

(Williamson; 6.1) (Supplementary Table 2). The abundance of some birds varied seasonally. *Coturnix coturnix conturbans* (Hartert) and *Serinus canaria* (Linnaeus) were more abundant in winter, whereas *F. c. moreletti* was the most abundant during the summer. *Estrilda astrild* (Linnaeus, Estrildidae), a species recently introduced in the

Azores was also observed in the area.

Characterisation of plant cover and species composition

Clethra arborea Aiton was the most frequent species (92% of plots), followed by *Blechnum spicant* (L.) Roth

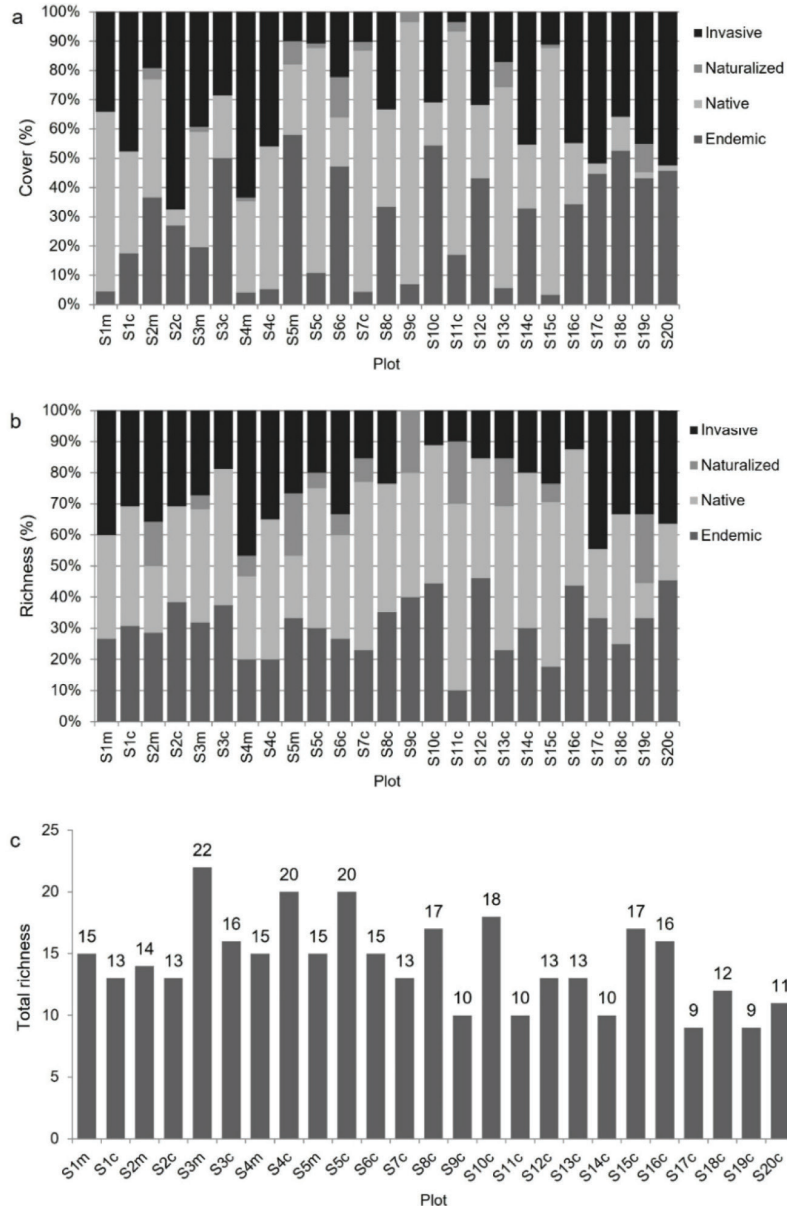


Fig. 3. Cover (a) and richness (b) percentages and total richness (c) inside each plot. The calculated mean of species richness was of 14 species.

(80%), *Calluna vulgaris* (L.) Hull (72%), *Laurus azorica* (Seub.) Franco and *Hedychium gardnerianum* Steph. Ex. Ker Gawl (60% each, Fig. 2a). *Ilex azorica* Gand. occurred in 44% of the plots. Many species occurred in fewer than 50% of plots ($\leq 12 / 25$). *Calluna vulgaris* showed the highest percent cover (18.45%), followed by *Clethra arborea* (15.34%), *L. azorica* with 13.4%, *Sphagnum* spp. and *I. azorica* (5–6%). The percent cover of the remaining species was below 4% (Fig. 2b).

Clethra arborea showed the highest importance, based on the contribution of both frequency and cover, followed by *Calluna vulgaris*, *B. spicant* and *L. azorica* (Supplementary Fig. 1).

Community composition

Cover percentage was higher for natives, followed by the in-

vasive plants, that dominated several marginal and core plots. On average, endemic species covered 28% of the plots, with greater percent cover in plots S3c, S5m, S6c, S10c and S18c (Fig. 3a, Table 1). The percent cover of naturalized species was very small. Species richness was higher for indigenous species (Fig. 3b, Table 1), largely due to the higher richness of native species (37.52%, averaging 5 species per plot, while the endemics averaged 4 species). A mean of 3.6 invasive species was recorded per plot (Table 1). Total richness varied between 9 and 22 species per plot, with an average species richness of 14 species (Fig. 3c). No clear pattern was observed between core and marginal plots, due to variations in the values.

Vegetation types

According to the dendrogram in Fig. 4, the cluster analyses based on Bray-Curtis dissimilarity coefficient and Ward's

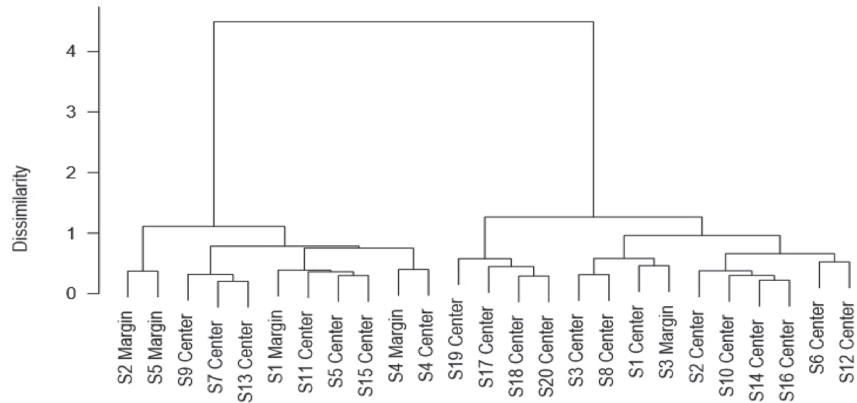


Fig. 4. Dendrogram representing the relationship between the 25 sampled vegetation plots.

Minimum Variance Clustering have divided the 25 plots into two main plant communities. Both the silhouette width and Pearson's Correlation approaches supported $k = 2$ clusters (average silhouette width = 0.3718; Pearson's correlation = 0.765). The dendrogram's cophenetic correlation coefficient (0.806) indicates a good representation of the dissimilarities. The PERMANOVA indicated significant differences in species composition between the two clusters identified in the hierarchical analysis ($R^2 = 0.45726$, $p = 0.001$). However, multivariate dispersion did not significantly differ among clusters ($F = 0.3945$, $p = 0.516$), suggesting similar within-group heterogeneity.

In terms of plant composition, the right branch of the dendrogram was composed of an arboreal vegetation, dominated by *L. azorica* and *Clethra arborea*, whereas the left branch was composed of *Calluna vulgaris* scrubland along with a diverse herbaceous layer.

Indicator species

Two types of plots were considered, marginal and core plots. Nine species with significant indicator value ($p <$

0.05) were found, with one being indicator species of core plots (*L. azorica*, $p = 0.044$) and the remaining 8 taxa being associated with marginal plots (Table 2).

Invasive dynamics of *C. arborea*

Clethra arborea presented the best correlation between DBH and number of tree annual rings (*Clethra arborea*: $R^2 = 0.8991$; *Ilex azorica*: $R^2 = 0.6022$; *Laurus azorica*: $R^2 = 0.5681$). The height of the invasive tree was slightly lower than that of both endemics. Despite the similarities in the maximum number of annual rings for the three species, the mean number of rings was higher in the endemics, first in *L. azorica*, then in *I. azorica*. (Fig. 5, Table 3).

SWOT analysis

The information regarding the SWOT analysis was based on field observations and data collected by the authors and can be found in Supplementary Table 3. The area presents several strength factors regarding the conservation of plant and avifauna species, that could possibly justify its inclu-

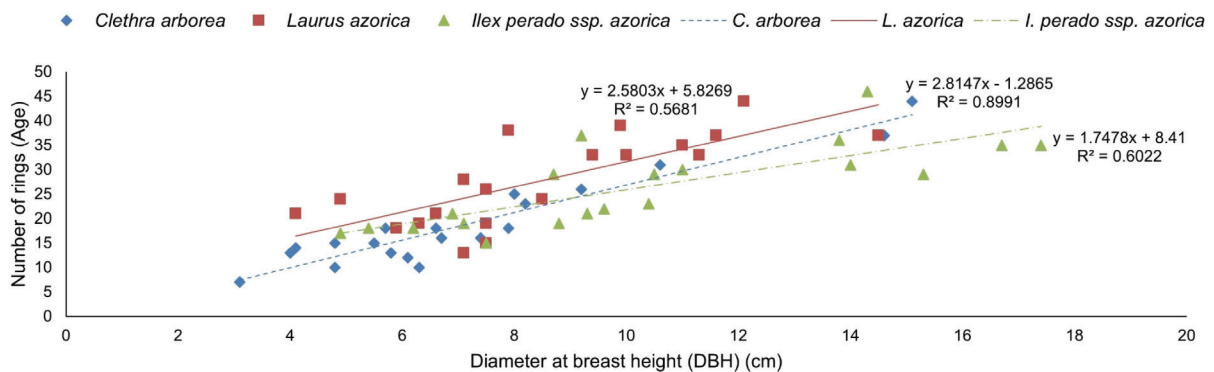


Fig. 5. Linear regression between DBH and number of tree annual rings for *Clethra arborea*, *Laurus azorica* and *Ilex azorica*.

Table 3. Dendrometric data obtained from *Clethra arborea*, *Laurus azorica* and *Ilex azorica*

	Mean DBH (cm)	Mean tree height (m)	Mean number of rings	Maximum number of rings
<i>C. arborea</i>	7.23	3.77	19.05	44
<i>L. azorica</i>	8.54	3.95	27.85	44
<i>I. azorica</i>	10.35	4.51	26.50	46

sion in the São Miguel network of Protected Areas. The presence of nearby bird watching sites constitutes opportunities for ecotourism activities. Most weaknesses and threats are related with the presence of invasive species and human activities in the surrounding areas.

Discussion

Characterisation of plant cover and species composition

In this area, indigenous species were more common in core plots, whereas the invasive species dominated marginal areas, near roads and the surrounding pastures. This likely reflects the greater exposure of margin habitats to anthropogenic disturbance, as previous studies have shown (SILVA and SMITH, 2006; QUEIROZ et al., 2014). A study demonstrated that pressures on these habitats turn them more vulnerable to soil disturbances and propagule pressure, decreasing native community resilience (MURILLO and WAGNER, 2025).

Our results identified two distinct plant communities occurring in the area, one being a *Laurus azorica*-dominated arboreal community and the other a *Calluna vulgaris* scrubland, with a diverse herbaceous layer. This was supported by the silhouette analysis, the strong cophenetic correlation coefficient obtained and by the indicator species analysis. Moreover, the significant result obtained in the multivariate analysis (PERMANOVA), combined with the non-significant PERMDISP, suggests that the differences between clusters are more likely attributed to shifts in species composition rather than unequal variability within groups (ANDERSON, 2001, 2006).

Regarding the arboreal *Laurus* community, the patterns exhibited suggest that the original vegetation would likely correspond to a *Laurus* submontane forest (ELIAS et al., 2016), which was subsequently altered by disturbance and plant invasion (given the dominance of invasive plants in several plots, particularly of *Clethra arborea*). *Clethra arborea* is an endemic species from Madeira Island, which commonly occurs in the “cloud zone vegetation” on the so called ‘*Clethro-Laurion*’ (SJÖGREN, 1972). This species was initially recorded in São Miguel Island in the 1960s (FRANCO, 1984) and it has expanded, being found in natural vegetation at altitude, up to 1,000 meters and in marginal habitats, such as river valleys and roads (SJÖGREN, 1972; 1973; MONIZ and SILVA, 2003).

The *Calluna vulgaris* scrublands are commonly distributed throughout the Azores, due of numerous ecological situations, and usually in association with other formations (DIAS, 1996), such as peat bogs (as found in the study area). This type of vegetation community likely reflects disturbed environmental conditions, as similar scrublands in the Azores have been disturbed by anthropogenic pressures such as land use practices and historical top-soil harvest for local pineapple cultivation (SANTOS, 2010). More recently, its use and harvest have been prohibited (SANTOS, 2010), and that may have allowed the consequent recolonization of this scrubland in this area, as reported for other

locations in São Miguel Island (DIAS, 1996).

Invasive dynamics of *Clethra arborea*

The dendrometric results suggest that the invasion of *Clethra arborea* may be relatively recent, due to the lower mean age of individuals (19.05 years), when comparing with the two endemic species. However, these values should be interpreted with caution, since ring counts obtained at breast height likely underestimate the total tree age. The presence of older *C. arborea* individuals, may suggest that previous disturbances could have facilitated the invasion and establishment of this species in the former *Laurus* forest (ELIAS et al., 2016; FERNÁNDEZ-PALACIOS et al., 2021). This interpretation is supported by ROZAS et al. (2023), who refer agriculture and livestock practices as drivers of disturbance in Canarian *Laurus* forests. Despite that, chronological evidence to support this claim is lacking. The young mean age of *L. azorica* trees (27.85 years) may also suggest a possible role of anthropogenic disturbance in the establishment of a younger secondary forest, according with similar observations made by MARTOS et al. (2019). Despite not being an indicator species for core plots, the high frequency and importance values obtained by *C. arborea* indicate that there is potential for this species to become dominant in this area, under the current environmental settings. Moreover, previous studies have found seeds of *C. arborea* in the droppings of Azorean birds, suggesting that spread of this invasive tree may be mediated by birds (HELENO et al., 2013).

The anthropogenic disturbance possibly plays a key role in the successful establishment of invasive plants in altered semi-natural communities (SILVA et al., 2008; BELLINI et al., 2024). Invasive species are commonly associated with farming practices (SILVA and SMITH, 2006; SILVA et al., 2008; BELLINI et al., 2024), such as those found surrounding the area. The successful establishment of *C. arborea* may also be related with the suitable climate and shelter provided by *Laurus* forests (DIAS, 1996; GARCÍA-LÓPEZ et al., 2025), or even due to ecophysiological factors (SILVA, 2001). However, the ongoing invasion process revealed by the results may result in further changes to the vegetation structure, transitioning from an arboreal to a shrub size vegetation, as reported by SILVA (2001).

Bird richness

A relatively high richness of bird species was recorded, including several endemic subspecies (MEDEIROS et al., 2008). This indicates that the study area supports a diverse assemblage of birds (despite *P. murina* not being sighted), possibly by the presence of a structurally diverse vegetation, which provides habitat and sources of food. However, the area remains currently disturbed by human activities, such as farming and hunting, to which birds are very sensitive. Previous works reported changes in the habitats and nesting places (due to fragmentation), with consequences on population size (MEDEIROS et al., 2005; NEWBOLD et al., 2014). MARCOLIN et al. (2024) highlighted that increasing

human pressures decrease the functional and phylogenetic diversity of native bird communities.

Thus, to support and conserve local bird communities, it is required to maintain and restore natural vegetation, which could potentially improve the resilience of native bird species (MARCOLIN et al., 2024). This is particularly relevant given that the vulnerable endemic *P. murina*, was possibly introduced near the study area, for breeding purposes, within the scope of past conservation projects, and was sighted in this location in previous years (BIRDLIFE INTERNATIONAL, 2016).

Importance of conserving unprotected natural areas in the Azores

The Azorean ecosystems present unique characteristics and geographic isolation, as well as ongoing ecological and evolutionary processes, which reinforce the need for a more urgent approach to the conservation of natural habitats and endemic species (GILLESPIE and RODERICK, 2002).

Within the scope of the Convention on Biological Diversity (CBD), the goal is to conserve at least 30% of the world's maritime and terrestrial areas, by 2030. A key aspect relies on Other Effective area-based Conservation Measures (OECMs) (JONAS et al., 2024), which are areas not classified as Protected Areas, but that can potentially contribute significantly to the conservation of biodiversity, ecosystems services and cultural, socio-economic and spiritual values (JONAS et al., 2024).

If efficiently managed, the study area could potentially be acknowledged as an OECM, because: (i) This area likely functions as an ecological buffer for nearby protected areas, as seen elsewhere (GRAZIANO et al., 2022; MI et al., 2023); (ii) High bird diversity and presence of endemic plants suggest this area holds some potential for sustainable nature-based tourism and birdwatching activities, which are increasing in the Azores (PONTE et al., 2018) and, if carefully managed, can contribute to creating awareness for the local conservation; (iii) Contribute to the conservation of a threatened Laurel forest in São Miguel (FLORENCIO et al., 2021), which provides important ecosystem services and harbours priority species for conservation (CARDOSO et al., 2008; PEREIRA et al., 2016); (iv) May contribute for the potential extension of the habitat of *P. murina* (BIRDLIFE INTERNATIONAL, 2016), due to the presence of suitable habitat (Laurel forest), and important winter food resources (RAMOS, 1995; VAN RIEL et al., 2000).

To improve the ecological state of this area, we make several recommendations based on the results. First, to control *Clethra arborea*, particularly with the aim of avoiding the formation of pure stands resulting from its ability to overgrow native trees due to a large biovolume (MONIZ and SILVA, 2003). The control of *C. arborea* was previously tested using mechanical, chemical and mixed approaches (SILVA et al., 1999; SILVA, 2001). However, the use of chemical treatments is discouraged, because it may result in bird poisoning (SILVA et al., 1999). The restoration of the natural vegetation habitats is important, and has been implemented recently, within the project LIFE

IP AZORES NATURA. Previous work suggested that passive restoration measures may be enough to regenerate degraded *Laurus* forests, following the abandonment of land-use related disturbances (ROZAS et al., 2023). Additional measures to restrict or mitigate the impacts of nearby anthropogenic activities, such as farming, animal grazing and introduction of species, and monitorization of natural areas should be considered. Environmental education is another proven concept worldwide (PANITSA et al., 2021), which is fundamental to raise public awareness towards biodiversity conservation. As an example, project LIFE IP AZORES NATURA implemented citizen science initiatives designed to teach citizens on how to detect, manage and control invasive species, by actively engaging in biodiversity and ecosystems protection. Other management actions to be explored could include the revision and improvement of the legal framework related with conservation and protected areas design, as well as further exploratory studies regarding an eventual addition of the study area into the São Miguel Island Natural Park.

This study demonstrates that there are still some natural habitats located outside the boundaries of protected areas, that are vulnerable and exposed to anthropogenic disturbance (COX and UNDERWOOD, 2011; GRAZIANO et al., 2022; REGO et al., 2024). Despite focusing on only one area, it opens for discussion that more natural areas throughout the Azores may contribute to support local biodiversity conservation, if appropriately managed (MOREIRA et al., 2018). Therefore, the need for assessing such areas is reinforced, and to integrate them in conservation strategies. Furthermore, a better understanding of the biology of endangered species should be the aim of future studies, allowing more effective policies for biodiversity conservation, in the future.

Conclusions

This work demonstrated that natural unprotected vegetation areas in São Miguel Island may still hold substantial conservation value for Azorean biodiversity. Two different plant communities were found in the study area: a *Laurus azorica* forest and a *Calluna vulgaris* scrubland with a rich herbaceous layer. Both communities likely reflect human disturbances related with historical land uses. Despite a possibly relatively recent invasion of *C. arborea*, with real potential for further expansion, the area still holds important endemic and native plant species, as well as a diverse bird assemblage possibly associated with the structurally heterogeneous vegetation.

Thus, the proximity of the site to protected areas, along with its role as a potential ecological buffer and habitat for endemic species, highlights its relevance for conservation planning. Through appropriate management actions, such as control of *C. arborea*, habitat restoration, and citizen science, this area could significantly contribute to support biodiversity conservation, potentially qualifying as an OECM, within the scope of the CBD's 30% goal, or

as a candidate for future integration in the São Miguel Island Natural Park.

Acknowledgements

The authors would like to thank António Moniz Medeiros, for the maps built and for other important contributions given during this research. This study was funded by national funds through the Foundation for Science and Technology (UIDB/50027/2020). We thank Direção Regional do Ambiente and Direção Regional da Ciência e Tecnologia for the permits obtained to conduct the field sampling (Lic. N.º 97/2020/DRA; SGC10/2020/714 / SAI-577/2020/DRCT).

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Received December 31, 2025

Accepted May 15, 2026

Supplementary materials

Table S1. List of vascular plant species (including the bryophytes found in 25 plots)

Status	Species name	Family
N	<i>Agrostis castellana</i>	Poaceae
NAT	<i>Athyrium filix-femina</i>	Athyriaceae
NAT	<i>Blechnum spicant</i>	Blechnaceae
NAT	<i>Calluna vulgaris</i>	Ericaceae
END	<i>Carex hochstetteriana</i>	Cyperaceae
INV	<i>Clethra arborea</i>	Clethraceae
N	<i>Cryptomeria japonica</i>	Taxodiaceae
NAT	<i>Culcita macrocarpa</i>	Culcitaceae
INV	<i>Dicksonia antarctica</i>	Dicksoniaceae
END	<i>Dryopteris affinis</i>	Dryopteridaceae
END	<i>Dryopteris azorica</i>	Dryopteridaceae
END	<i>Erica azorica</i>	Ericaceae
INV	<i>Erigeron karvinskianus</i>	Asteraceae
END	<i>Festuca francoi</i>	Poaceae
N	<i>Fragaria vesca</i>	Rosaceae
INV	<i>Gunnera tinctoria</i>	Gunneraceae
END	<i>Hedera azorica</i>	Araliaceae
INV	<i>Hedychium gardnerianum</i>	Zingiberaceae
END	<i>Holcus rigidus</i>	Poaceae
NAT	<i>Huperzia selago</i>	Lycopodiaceae
INV	<i>Hydrangea macrophylla</i>	Hydrangeaceae
NAT	<i>Hymenophyllum tunbrigense</i>	Hymenophyllaceae
END	<i>Hypericum foliosum</i>	Hypericaceae
END	<i>Ilex azorica</i>	Aquifoliaceae
END	<i>Laurus azorica</i>	Lauraceae
END	<i>Leontodon rigens</i>	Asteraceae
N	<i>Leontodon saxatilis</i>	Asteraceae
INV	<i>Leycesteria formosa</i>	Caprifoliaceae
NAT	<i>Lycopodiella cernua</i>	Lycopodiaceae
END	<i>Lysimachia azorica</i>	Primulaceae
NAT	<i>Myrsine africana</i>	Myrsinaceae
NAT	<i>Osmunda regalis</i>	Osmundaceae
INV	<i>Pittosporum undulatum</i>	Pittosporaceae
N	<i>Plantago lanceolata</i>	Plantaginaceae
END	<i>Polypodium azoricum</i>	Polypodiaceae
NAT	<i>Polytrichum commune</i>	Polytrichaceae
NAT	<i>Potentilla erecta</i>	Rosaceae
N	<i>Potentilla indica</i>	Rosaceae
INV	<i>Pteridium aquilinum</i>	Dennstaedtiaceae
NAT	<i>Pteris incompleta</i>	Pteridaceae
INV	<i>Rubus ulmifolius</i>	Rosaceae
N	<i>Scrophularia auriculata</i>	Scrophulariaceae
NAT	<i>Selaginella kraussiana</i>	Selaginellaceae
NAT	<i>Sphagnum spp.</i>	Sphagnaceae
END	<i>Vaccinium cylindraceum</i>	Ericaceae
END	<i>Viburnum treleasei</i>	Caprifoliaceae
NAT	<i>Woodwardia radicans</i>	Blechnaceae

END – Endemic; NAT – Native; N – Naturalized; INV – Invasive.

Table S2. List of bird species and average number of sightings per transect (\bar{x})

Species name	Family	\bar{x}
<i>Buteo buteo rothschildi</i>	Accipitridae	0.9
<i>Columba palumbus azoricus</i>	Columbidae	1.7
<i>Coturnix coturnix conturbans</i>	Phasianidae	2.6
<i>Erethacus rubecula</i>	Muscicapidae	6.7
<i>Estrilda astrild</i>	Estrildidae	0.8
<i>Fringilla coelebs moreletti</i>	Fringillidae	8.1
<i>Larus michahellis atlantis</i>	Laridae	1.2
<i>Motacilla cinerea patriciae</i>	Motacillidae	3.1
<i>Passer domesticus</i>	Passeridae	1
<i>Regulus regulus azoricus</i>	Regulidae	2.6
<i>Serinus canaria</i>	Fringillidae	4.8
<i>Sturnus vulgaris granti</i>	Sturnidae	3.3
<i>Sylvia atricapilla atlantis</i>	Sylviidae	6.1
<i>Turdus merula azorensis</i>	Turdidae	4.8

Table S3. SWOT analysis made to assess the conservational potential of the study area

<p>Strengths</p> <p>The presence of many endemic and native elements, including plants, bryophytes and lichens;</p> <p>Presence of peat bogs, important in water capture;</p> <p>The proximity to roads, easy access for observation, monitoring and conservation;</p> <p>The proximity of protected areas (Furnas Protected Landscape and Tronqueira and Planalto dos Graminhais Protected Areas);</p> <p>The diversity of the landscape surrounding the area, including pastureland, native vegetation and production forest;</p> <p>Relatively high number of bird species;</p> <p>Only <i>Clethra arborea</i> is the major invader at the central areas, allowing a more direct control of its populations.</p>	<p>Weaknesses</p> <p>Deposition of residues close and inside the area;</p> <p>Several invasive species in the margin areas;</p> <p>Lack of present management.</p>
<p>Opportunities</p> <p>The growing interest in the Azores as a nature destination;</p> <p>The increasing interest in nature trails and the possibility of making a small trail from the base up to the most elevated point;</p> <p>The possibility of articulation with other interest sites, such as Pico do Ferro and Salto do Cavalo;</p> <p>The area has presently no extractive activities;</p> <p>The possibility of leaving some <i>Clethra arborea</i> trees, as a food resource to <i>P. murina</i>;</p> <p>The possibility of the extension of the potential habitat for <i>P. murina</i>;</p> <p>Activities devoted to bird watching.</p>	<p>Threats</p> <p>The potential expansion of the invasive species;</p> <p>The transformation of the area into production forest;</p> <p>Lack of management initiatives by the environmental authorities.</p> <p>Presence of farming activities (agriculture, animal grazing) in the areas around the study area.</p>

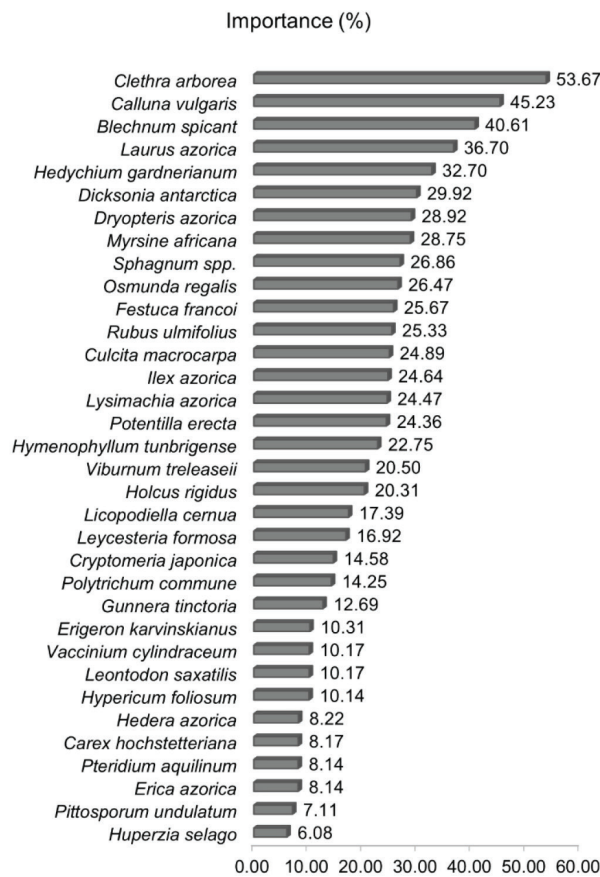


Fig. S1. Importance percentage of each species calculated based on the contribution of frequency and cover. Only the species with importance > 5% were considered for the Figure.