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LIFE Natura@night

Final report on bats survey on Natura 2000 areas

Funchal, December, 2023

COFINANCIAMENTO

PARCEIROS

COORDENAÇÃO

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In the **LIFE Natura@Night**, the main aim is to

Reduce and mitigate the impact of light poluition

In the Nature 2000 areas in Macaronesia.

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Missão

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Preliminary report on bats survey on Natura 2000 areas

Sociedade Portuguesa para o Estudo das Aves, 2023

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SUMMARY

In the LIFE Natura@night project (action A8), we surveyed the bat communities in the different types of habitats in Macaronesia of the Natura 2000. This study helped us complement the information about the bat population on the areas of the project. In Macaronesia, we can find c.a. 15 species (including species from Cape Verde), three endemic species: *Pipistrellus maderensis*, *Plecotus teneriffae* and *Nyctalus azoreum*. During Autumn of 2022, we conducted acoustic survey using AudioMoth passive acoustic recorders in the R2000 areas in Madeira Island and in Spring 2023 in Graciosa Island, Azores Archipelago. All field work was concluded in May 2023 and the analysis is processed. The mist-netting captures were done during spring in Madeira Island and Azores on the same areas where the acoustic surveys took place. In total only two bats were captured during the capture surveys (both in Madeira Island in Laurel Forest). In Madeira Island, a prevalence of the *P. maderensis* in Laurel Forest is very clear and the number of the detections of this species is considerably higher than the number of *N. leisleri*. In Graciosa, Azores Archipelago, the opposite happened with greater activity and distribution of *N. azoreum* than *P. maderensis*. In the Canaries, the data provided was analyzed and the description of the species present in the protected areas were made with greater species richness in Tenerife Island. Unfortunately, no comparative analysis between Canaries and the other archipelagos were possible yet with the data provided.

1. INTRODUCTORY NOTE

1.1 LIFE Natura@night

Artificial Light at Night (ALAN) plays a crucial role in modern society, providing safety for its populations. However, its excessive use might have negative impacts on the environment, leading in some cases to the death of various animals such as sea birds. The implications of ALAN on the ecosystems and the unknown impacts on Macaronesia resulted on the creation of **LIFE Natura@night Project** in March 2022 to mitigate the effects of ALAN in the region.

The project aims to understand and mitigate the effects of ALAN on the biodiversity of protected areas such as Nature 2000 areas in the Azores, Madeira and Canary Archipelagos. The Macaronesian region, according to IUCN, is home to ca. 789 threatened species and ca. 481 species are animal. Among nocturnal animals, there are ca. 177 insect species, eight marine bird species and five bat species considered threatened and potentially affected by ALAN.

However, the precise effects of ALAN on these nocturnal animals are unclear in Macaronesia and further studies are needed to understand this issue. The project has the main aim of decreasing the light pollution in these regions and mitigating the effects of ALAN on the protected species. Bat species in Macaronesia are categorized as threatened by IUCN Red List and more information is crucial for the conservation of these species especially in the Natura 2000 areas.

1.2 Macaronesian Bats

Chiroptera is considered the second largest mammal group globally, with over 1,400 species (Simmons et al., 2021). Bats have diverse dietary patterns ranging from carnivores to frugivorous and can be present in all the continents except for the poles. This makes this group of animals a hugely distributed group and essential for many ecosystems (Patterson et al., 2003, Altringham, 2011). Insectivorous bats are important bioindicators and contribute to maintain the balance of insect populations including agriculture pest and disease vectors (Jones et al., 2009a; Kunz et al., 2011; Ramírez-Fráncel et al., 2022). A significant number of these species can be found in insular ecosystems (ca. 60%) with many of them being endemic to islands (ca. 25%; Jones et al., 2009b; Conenna et al., 2017). However, according to IUCN, ca. 50% of

the insular bat species are threatened and five species have gone extinct (Jones et al. 2009b, Conenna et al. 2017, IUCN 2018).

Macaronesia is a biogeographical region in the Atlantic Ocean, consisting of five archipelagos with a total of 39 islands larger than 1 km^2. This region comprises archipelagos from different countries such as Portugal (Azores, Madeira and Salvages Archipelago at the north), Spain (Canary Archipelago) and Cape Verde (south) (Masseti, 2010). Due to the diversity of habitats and climates, Macaronesia is recognized as a hotspot of biodiversity, home to numerous endemic species (Whittaker & Fernández-Palacios 2007; Brilhante et al. 2021, Florencio et al. 2021). However, the terrestrial mammal species are mainly the 16 bat species (native) and introduced mammals (Masseti, 2010). Macaronesia is home to three endemic species: Azorean Bat (*Nyctalus azoreum*, Thomas 1901) restricted to Azores; Madeiran Pipistrelle (*Pipistrellus maderensis*, Dobson 1878) found in Azores, Madeira and Canary Archipelagos; and Canary Long-Eared Bat (*Plecotus teneriffae*, Barret-Hamilton 1904) restricted to the Canaries. According to IUCN, all these endemic species are classified as Vulnerable.

As verified in the Action A5 - Review on the effects of ALAN in bats in with special focus on the Macaronesia Region, the effect of light pollution on bats in Macaronesia is currently unknown and further research is needed to understand its impact. The LIFE Natura@night, strongly associated to the Natura 2000 areas, aims to determine the best methods to mitigate the effects of the current illumination plan and evaluate the benefit of the new ones. Conducting research on the bat populations on the region is essential to achieve this goal and understand the population dynamics in these areas. Therefore, action A8 aims to characterize bat communities in Natura 2000 areas targeted by the project that can potentially benefit from the reduction of light pollution.

2. Methodology

2.1 Technical Aspects

We conducted an assessment of bat activity and diversity within the areas of Natura 2000 targeted by the project (16 locations, 48 recording sites). The research was carried out in the same areas targeted by Action A9 – Identification of the presence of endemic nocturnal insects on Natura 2000 areas covered by the project - for

comparative analysis. To ensure consistency, we standardized methodologies for bioacoustics and mist-netting across Madeira and Graciosa Island (Madeira and Azores archipelagos). The bat data from Canary Archipelago based on georreferenced bibliographical data ("Banco de Datos de Biodiversidad de Canarias") and did not include field work.

2.2. Study Areas

2.2.1 Azores Archipelago: Graciosa Island

The Azores archipelago consists of nine volcanic islands located ca. 1,400 km off mainland Portugal (Fig. 1). These volcanic islands are located between tectonic plates and experience constant volcanic activity. Graciosa Island is a small island (ca. 62 km^2), formed around 2.5 My ago (Rando et al., 2017). Although the island's highest point reaches ca. 402 m altitude, most of the land is situated at lower altitudes (under 300 m altitude; Teixeira et al., 2015). Graciosa is characterized for its low forest cover and high concentrations of introduced flora such as *Pittosporum ondutatum* (Silva et al., 2004; Teixeira et al., 2015). This is due to the island's easy terrain for anthropogenic occupation (Reno et al., 2015). Unlike the other islands in the archipelago, Graciosa lacks natural water sources. Agricultural areas are the predominant land use on the island according to the Coordination of Information on the Environment CORINE Land Cover (CLC) (Castanho et al., 2006).

Figure 1 *Location of the Archipelago of Azores*

2.2.2 Madeira Archipelago: Madeira Island

Madeira Archipelago is composed by Madeira, Porto Santo, and Desertas Islands, situated c.a. 700 km off the African coast (Fig. 2). The main island (Madeira) is c.a. 742 km^2 and emerged c.a. 7 – 5 Ma years (Ramalho et al., 2015; Góis-Marques et al., 2019). The highest peak on Madeira Island reaches an altitude of 1,862 m, making it a highly mountainous region. Its diverse microclimates contribute to a wide range of habitats on the island (Delgado et al., 2006). Despite being prone to wildfires and other natural disasters, the island sustains ca. 6.8% of its endemism density level (Castanho et al., 2019; Masseti & Gil, 2020). Madeira island also holds the highest endemism density levels of all Macaronesia with over 7500 plant species either endemic to the archipelago or Macaronesia (Borges et al., 2008; Masseti & Gil, 2020). Even though agriculture is a huge source for the Madeiran Economy, the Forest and semi-natural areas occupy the largest extension of the island (Castanho et al., 2021).

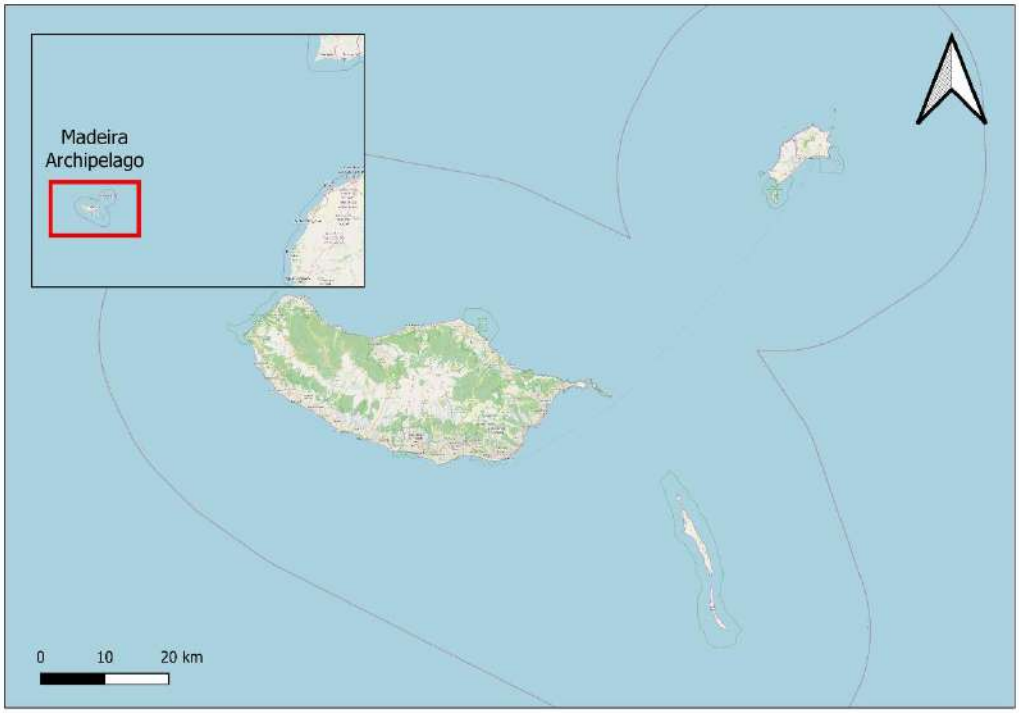


Figure 2 Location of Madeira Archipelago.

2.2.3 Canary Archipelago

The Canary Archipelago consists of eight volcanic islands and numerous islets, located approximately 100 km northwest of the African coast (Fig. 3). The islands' elevations vary from 671 m (Lanzarote) to 3,718 m (Tenerife), resulting in a wide range of vegetation types across the archipelago. The islands closer to the east are influenced by the winds from the Sahara Desert, creating a xerophytic climate at lower altitudes. In contrast, the higher mountainous islands feature diverse vegetation, including humid forest habitats like the Laurel Forest and dry monospecific pine forests found at higher elevations (Nogales et al., 2006).

Figure 3 *Location of Canary Archipelago.*

2.3. Bioacoustic Survey

In both Madeira and Azores, extensive efforts were made to conduct bat surveys using automatic ultrasound recording devices (Audiomoth v.1.2.0) in the Natura 2000 areas (14 in Madeira and two in Graciosa). In Madeira Island the recorders were placed from August till October 2022 while in Azores the survey took place in the beginning of April 2023. In each sampling area, three Audiomoths were positioned c.a. 100 to 300 m from each other (46 and 6 recording points in Madeira and Graciosa, respectively, Fig. 4A,B). Additionally, in Graciosa an island-wide survey was carried out with ca. 60 acoustic random points distributed across the entire island (Fig. 4C).

The Audiomoths were set to record up to 384 kHz from 15 before the sunset until 15 min after sunrise coinciding with the same areas where the insect survey areas. In the case of the island-wide survey, the Audiomoths were set to record for 24 hours, one minute out of five due to the diurnal activity of *N. azoreum*. This comprehensive approach aimed to maximize the chances of detecting bat activity and gathering a comprehensive soundscape across the entire island.

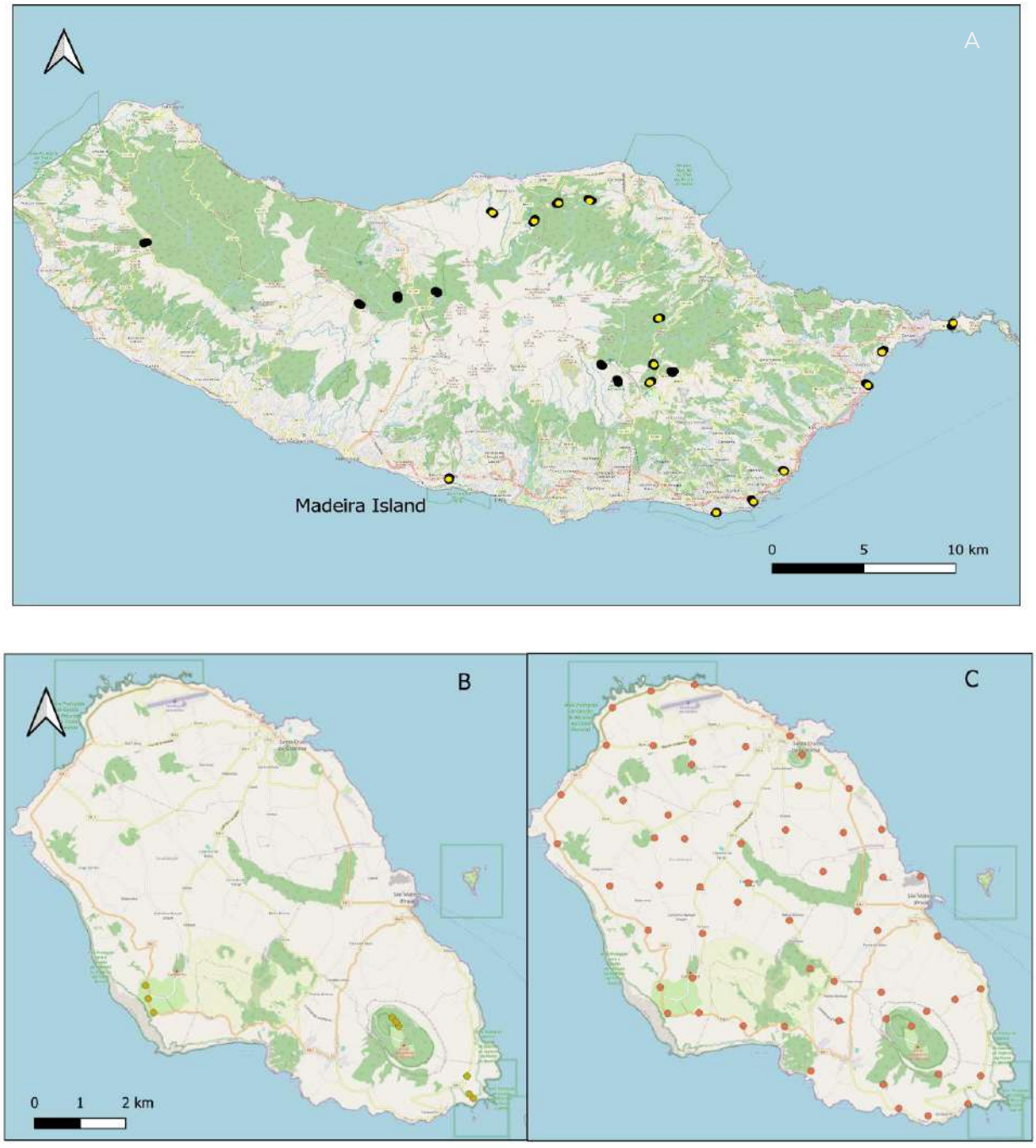


Figure 4 Placemente of the Audiomoths in Madeira and Graciosa Island, Portugal. The black dots represent the areas where Audiomoths were placed, the yellow dots represent the capture sites and no captures were done on the extra points (A), Audiomoth placement in the Graciosa Island (Azores) in the Natura 2000 areas (B) and the extra points across the island (C)

The recorders were affixed to various structures such as poles, trees, shrubs, and even inserted into wall crevices. The recorders were positioned at a height ranging from 1 to 2 meters. Despite the difficulties in finding suitable locations,

every effort was made to ensure the recorders were securely positioned, allowing for accurate and reliable recording of bat activity (Fig. 5).

Figure 5 Placement of the Audiomoths in the field (Copyright to Yasmin Redolosis).

2.4 Bioacoustic Analysis

The recorded data was carefully analyzed using Kaleidoscope Pro, utilizing the AutoID program to facilitate the identification of bat species present in the recordings. To ensure accuracy, the results generated by the AutoID program were subjected to manual verification.

To assess the activity of bats, a detailed analysis was conducted focusing on bat passes. A bat pass was defined as a sequence of two or more echolocation pulses that occurred within a five-second sound file. By examining these bat passes, valuable insights into the behavior and patterns of bat activity were extracted and analyzed. This meticulous approach allowed for a comprehensive understanding of the presence and behaviors of bats within the surveyed areas.

2.5 Mistnetting and Captures

During March - May 2023, surveys conducted in the Natura 2000 areas, the capture areas were strategically chosen to align with the research areas used to survey nocturnal insects (Action A9). We used ground-level mist nets were used ranging from 3 and 12 m in length in the selected areas (Table 1). Whenever possible, the nets were positioned in strategical areas such as potential foraging areas or drinking areas, maximizing the changes of capturing bats (Fig. 6).

The total number of nets used varied depending on the specific site, taking into consideration the availability of suitable areas and sufficient space for net placement. Between four and five nets of different lengths were used in each capture area. In rare instances, only three nets were placed due to specific circumstances such as space and terrain.

The capture and handling of bats strictly followed the recommendations approved by the American Society of Mammalogists (Sikes et al., 2011). All bats captured were released at the capture site. No surveys or captures were conducted on rainy or windy days and precipitation and wind speed were constant throughout the sampling period.

Additionally, during the captures a Echometer was used to detect the presence of bats close to the mist nets.

Figure 6 Placement of nets for the captures (A), Captures at the Caldeira (B), Captures at the Farol do Carapacho (C) (Copyright to Yasmin Redolosis).

Mist nets were set up and opened before sunset and remained in place for approximately four to five hours depending on the bat activity and the most active times. Additionally, in the capture nights a Audiomoths and a Echometer were used to determine the presence of bats near the capture areas. These devices help detect and verify the presence of bats in the capture areas during the survey.

Table 1 *Data on the Nets placed on each study area and the measures of the nets used in each area.*

Archipelago	Study area	Point	N. nets	3 m	6 m	9m	12 m
Madeira	Cabo Girão (PTMAD0011)	1	3	0	2	1	0
	Pináculo (PTMAD0007)	1	3	1	2	0	0
	Caniço de Baixo (PTMAD0012)	1	3	2	1	0	0
	Porto Novo (PTMAD0013)	1	4	1	3	0	0
	Machico (PTMAD0014)	1	4	0	3	1	0

	Pico do Facho (PTMAD0015)	1	4	2	0	0	2
	Ponta de São Lourenço (PTMAD0003)	1	5	1	3	1	0
	Maciço Montanhoso central (PTMAD0002)	10	5	1	4	0	0
		11	5	1	3	0	1
	Laurissilva (PTMAD0001)	5	4	0	1	2	1
		6	3	1	2	0	0
		7	4	0	3	0	1
		8	4	1	2	1	0
		9	5	1	4	0	0
Azores	Carapacho /Ilhéu de Baixo (PTZPE0029)	1	4	0	4	0	0
	Caldeira	1	3	0	3	0	0
	Pico Branco (PTGRA0016)	1	4	0	4	0	0

2.6 Equipment required

The majority of the fieldwork materials were acquired from Ecotone. The materials for the bioacoustic arrived during autumn (September - October 2023) and the remaining during Spring (beginning of April). The following list of materials were acquired for this action:

- Mist nets (3, 6, 9 and 12 m length)
- Telescopic poles
- Ropes
- Pickets
- Cotton bags
- Audiomoths
- Audiomoth cages
- Batteries
- Micro SD cards
- Battery Rechargers
- Kaleidoscope Pro Licence
- Echometer

- Song Meter Mini

2.7 Methodology in Canaries

Fieldwork was not required for the Canary Archipelago due to data accumulated from 1859 to 2022 across the islands, although the most specific studies have been carried out in the last three decades. The studies conducted were systematically compiled and stored within the database "Banco de Datos de Biodiversidad de Canarias"[1]. These studies were meticulously categorized based on precision levels, ranging from 1 (most precise) to 5 (less precise), and confidence levels (secure or doubtful). Among the 158 refences of the different bat species in papers collected, 90 were classified as highly precise (level 1), 59 as precise (level 2), with 5 and 4 falling into the less precise categories (levels 3 and 4) (Supplementary Material - A). Only two papers were considered doubtful, while the remaining 156 provided secure data. The methodologies employed in the different papers included bioacoustics, captures, colony monitoring, etc.

The data from the categories 1 and 2 was amalgamated to generate a species distribution map of the Canary Islands, in 500 by 500 m grids. The shapes depicted on map displaying species distribution were the tool used to verify the presence of the different bat species in the protected areas and across the islands of the archipelago.

3. RESULTS AND DISCUSSION

3.1 Azores

The recordings conducted at Farol do Carapacho (Ilhéu de Baixo, GRA1) yielded only two bat passes of *P. maderensis* and a significant number of 1,880 bat passes of *N. azoreum* (Fig. 7). However, during the captures in the area, only one bat was observed flying around the lighthouse and no bats were captured.

In the Ilhéu de Baixo area, most of the detections were recorded close to the lighthouse, which coincides with the capture location (Fig. 8). However, the captures took place during the first hours of the night (before midnight), and most bat passes were recorded in the area during the early morning hours (from 1:00 AM till 6:00 AM). The recordings of *P. maderensis* (2 bat passes) were recorded close to the

[1] https://www.biodiversidadcanarias.es/biota/

lighthouse as well (Fig. 7). Due to the weather conditions and the high exposition on the islets, no bat recordings were done on these Natura 2000 areas.

On the other hand, the Caldeira (GRA2), characterized by abundant tree vegetation, with a small water source and protected from the ocean, exhibited a lower overall bat activity compared to the lighthouse area. However, both species were detected (*P. maderensis* and *N. azoreum*), with *P. maderensis* showing higher prevalence (Fig. 7). In the Caldeira, bats were recorded during the captures with the help of a Echometer (*P. maderensis* and *N. azoreum*). The three Audiomoths recorded uniformly the activity of *P. maderensis* and *N. azoreum*. The tree recorders detected both species in this area (Fig. 7).

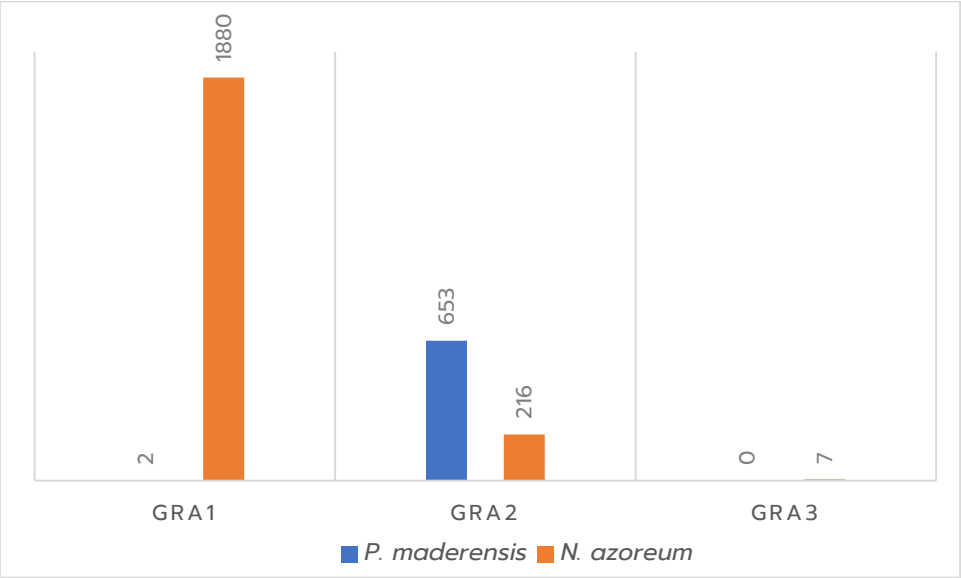


Figure 7 Bat Detections per site on the Natura 2000 areas (GRA1: Farol do Carapacho; GRA2: Caldeira, GRA3: Pico Branco).

Lastly, in the wind-swept grassland area located on Pico Branco (GRA3), only seven bat passes were detected, indicating that bat activity might be more dispersed away from the coastline (Fig. 5). In GRA3, *N. azoreum* was the only species detected on the recorders. During the captures, no bats were detected visually but *Nyctalus azoreum* were detected on all the points in the area (Fig. 8).

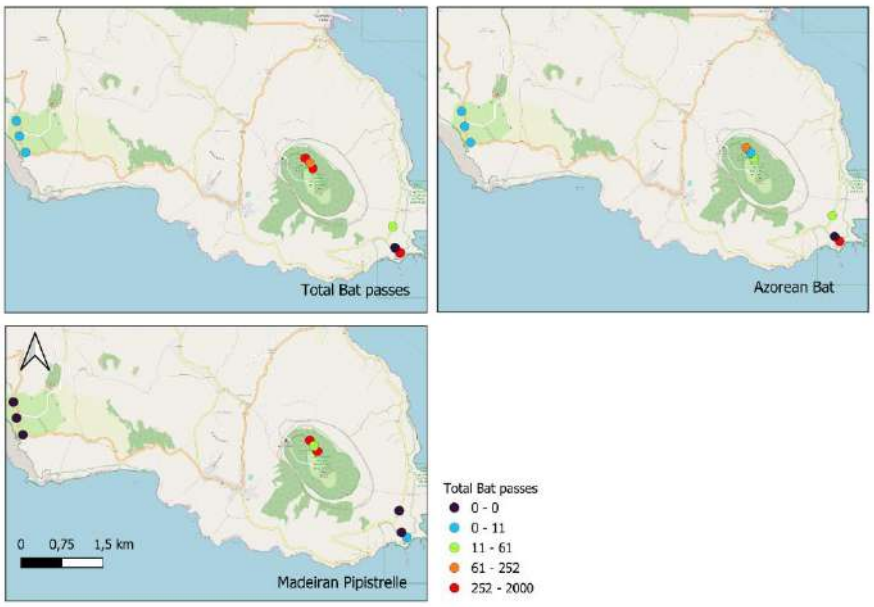
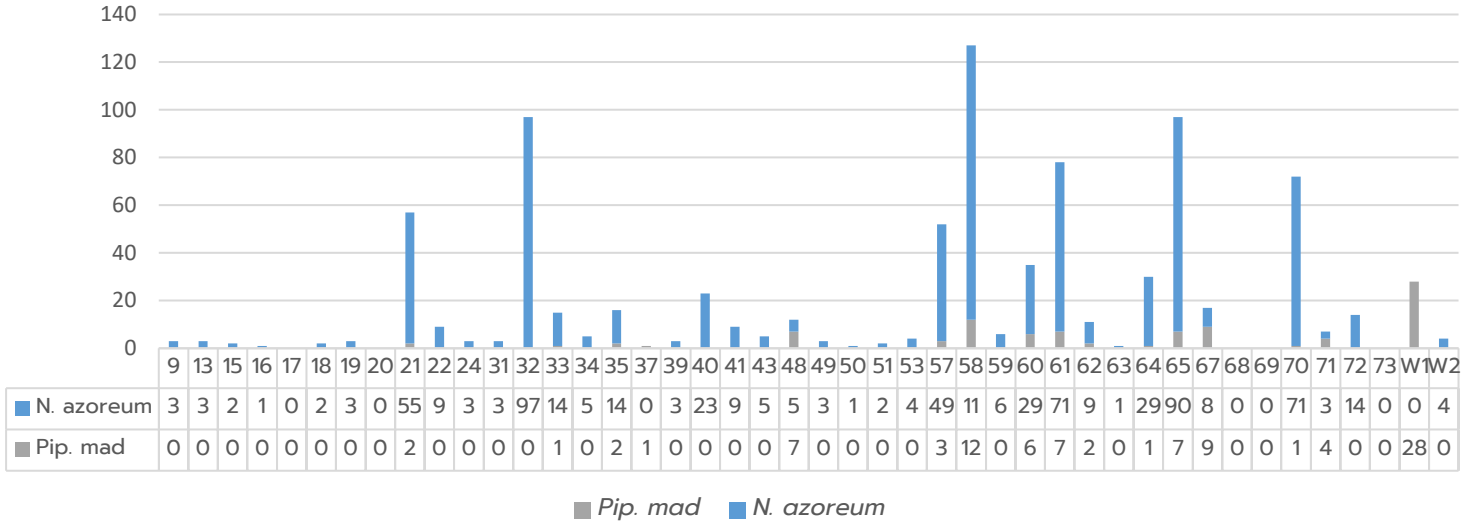


Figure 8 Bat passes per AudioMoth on the areas of RN2000. Total number of bat passes (top left), Azoream bat (top right), Madeiran pipistrelle (bottom).

During the research survey in Graciosa, approximately 60 additional recording sites were established (Fig. 4C). Among the recorded bat species, *N. azoreum* displayed the widest distribution and highest activity levels (Fig 9, 10), and was detected on 36 recording sites (ca. 63,3%). The data collected suggests that bat activity was predominantly concentrated on the north and east sides of the island, particularly on the case of the *N. azoreum* (Fig. 9).



	9	13	15	16	17	18	19	20	21	22	24	31	32	33	34	35	37	39	40	41	43	48	49	50	51	53	57	58	59	60	61	62	63	64	65	67	68	69	70	71	72	73	W1	W2
N. azoreum	3	3	2	1	0	2	3	0	55	9	3	3	97	14	5	14	0	3	23	9	5	5	3	1	2	4	49	11	6	29	71	9	1	29	90	8	0	0	71	3	14	0	0	4
Pip. mad	0	0	0	0	0	0	0	0	2	0	0	0	0	1	0	2	1	0	0	0	0	7	0	0	0	0	3	12	0	6	7	2	0	1	7	9	0	0	1	4	0	0	28	0

Pip. mad *N. azoreum*

Figure 9 Number of bat passes per recorded site where bat passes were identified per species.

Pipistrellus maderensis, on a first map analysis, seems to be located close to city areas of Graciosa as well as forest areas. The species was detected on 17 out of the 60 recordings sites (ca. 28.3%). Most sites where *P. maderensis* were detected had up to 10 bat passes and in the Caldeira area the highest number of bat passes were detected from the species (28).

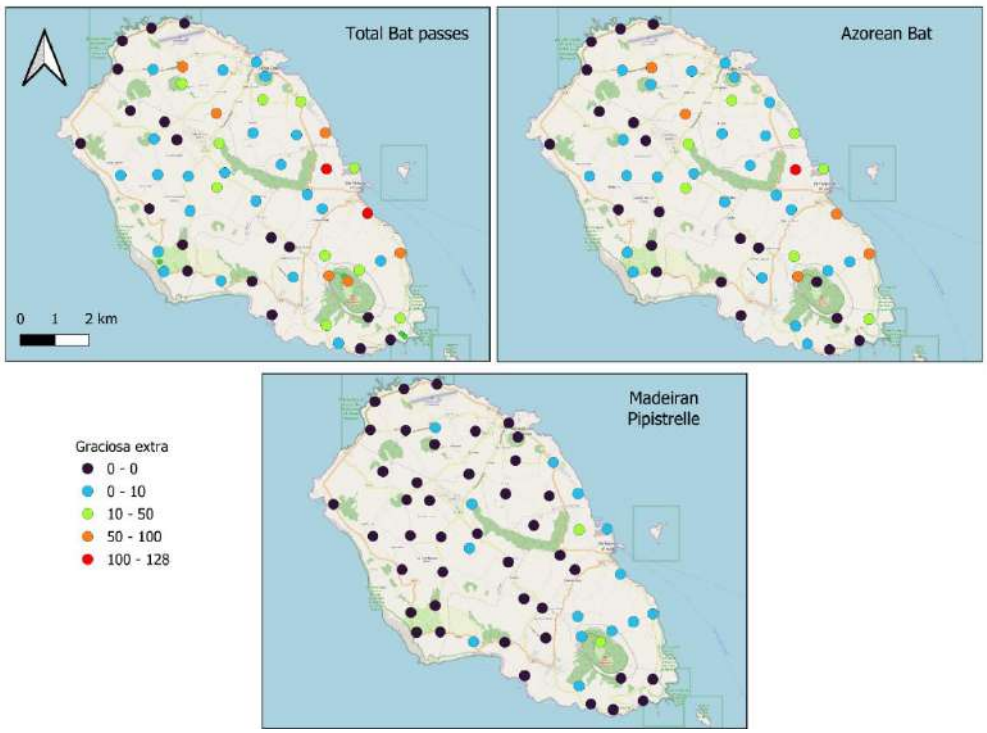


Figure 10 Bat passes in extra recording sites throughout Graciosa island. Total number of bat passes (top left), bat passes of Azorean bat (top right) and Madeiran pipistrelle (bottom).

Both species were observed together at 14 recordings sites (ca. 23.3%), and both were absent on 20 (ca. 33.3%). In ca. 25 sites (ca. 41.7%), only one species was detected with *N. azoreum* present in 22 (22 out of the 36 sites where the species was detected) and *P. maderensis* in 3 (3 out of 17 sites).

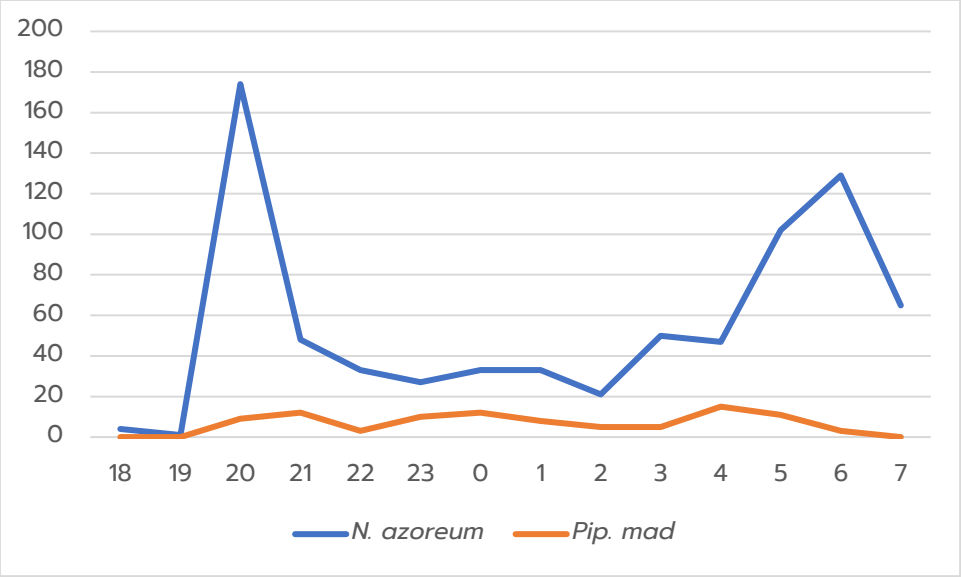


Figure 11 Bat passes per time of the day for each of the species in Graciosa Island (*N. azoreum* in blue and *P. maderensis* in orange).

Given the limited frequency of *P. maderensis* detections, determining the activity patterns of the species in the island remains inconclusive. In contrast, observations show that *N. azoreum* has peaks of activity during the beginning of the night and the early morning (Fig. 11). Notably, there were no recorded instances of bat activity during the daytime in Graciosa Island.

3.2. Madeira

During the research conducted on Madeira Island, only two individuals of the species *P. maderensis* were captured (Fig. 12). However, it is worth noting that the second individual managed to escape the net before being processed. Both captures took place in Laurissilva forest, one in LS6 and another one in LS2.

Figure 12 Male *P. maderensis* captured in Laurel Forest.

The data collected reveals a distinct pattern of distribution of the bat species in the various locations of Madeira Island. In areas such as Machico, Cabo Girão, Pináculo, Pico do Facho and Ponta de São Lourenço, the prevalent species detected with the recorders were *N. leisleri*. On the other hand, in Caniço Baixo, Laurissilva, Maciço Montanhoso Central and Porto Novo were *P. maderensis* (Fig. 13).

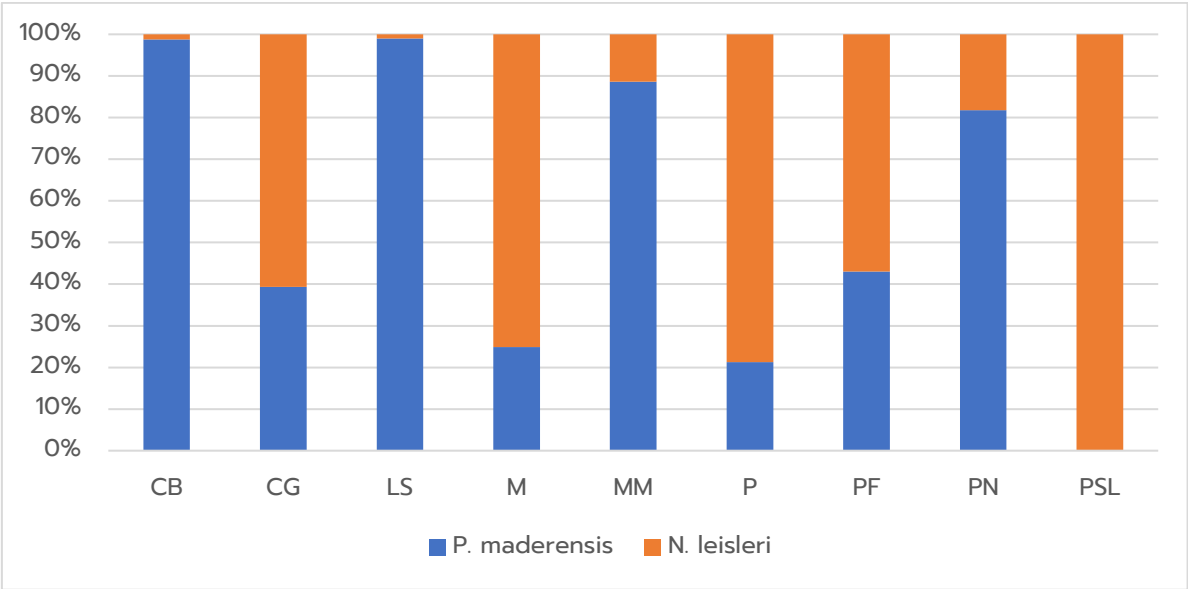


Figure 13 Percentages of species bat passes per study area. CB: Caniço de Baixo, CG: Cabo Girão, LS: Laurissilva, M: Machico, MM: Maciço Montanhoso Central, P: Pináculo, PF: Pico do Facho, PN: Porto Novo, PSL: Ponta de São Lourenço.

Cabo Girão is a coastal area near a city area and characterized by the presence of *Eucalyptus* sp. trees. In this location (Fig. 14), it was possible to detect both species with a total of 216 bat passes during the night: 85 *P. maderensis* and 131 *N. leisleri*. The maximum number of bat passes detected on a single recorder was 79 detections of *N. leisleri,* while the lowest was two *P. maderensis* bat passes. On the day of the captures, the recorder placed detected more *P. maderensis* (35 bat passes) than *N. leisleri* (5), however no bats were captured during this night.

Figure 14 Number of bat passes per site on Cabo Girão. Total Number of bat passes per site (Background), Madeiran Pipistrelle (top right), Leisleri's Bat (bottom left).

The south Madeira areas (Pináculo, Caniço de Baixo, Porto Novo) are mainly urban areas with low vegetation, occasionally featuring fruit trees. All recorders detected *P. maderensis* and *N. leisleri* (Fig. 15).

In Pináculo, *N. leisleri* (max. 821 and min. 29 bat passes per recorder) was more detected than *P. maderensis* (max. 95 and min 89 bat passes per recorder). During the captures, no bats were captured, however *P. maderensis* was detected with the help of the Echometer (Fig. 15).

In Caniço de Baixo, *P. maderensis* (max 1341 and min 11 bat passes per recorders) was detected more than *N. leisleri.* (max. 9 and min 1 bat passes per recorders; Fig.

15). During the captures, no bats were captured however only *P. maderensis* were detected with Audiomoth (13 bat passes).

In Porto Novo, more bat passes from *P. maderensis* (max. 403 and min 72 bat passes per recorder) than *N. leisleri* (max. 66 and min 19 bat passes per recorder, Fig. 15). During the captures no bats were captured, no bats were detected on the furthest net from the route (Audiomoth) however *P. maderensis* was detected with the Echometer close to the route.

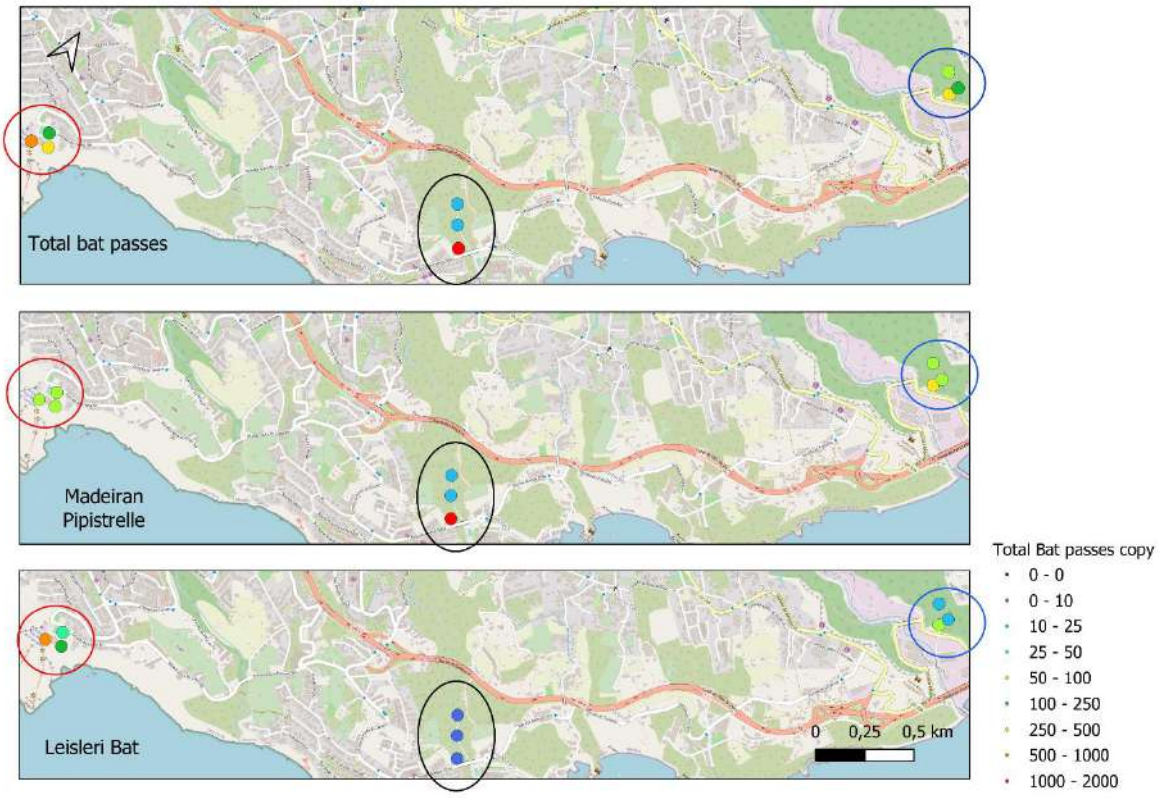


Figure 15 Number of bat passes per site on South areas of Madeira Island. Total Number of bat passes per site (top), Madeiran Pipistrelle (middle), Leisleri's Bat (bottom). Pinaculo (red circle), Caniço Baixo (black circle) and Porto Novo (blue circle).

On the mountain area (Maciço Montanhoso central), *P. maderensis* appear to be more active than *N. leisleri* (Fig. 16). The extra points where the recorders were placed in the Mountain areas were covered by shrubland (heathers) and a low tree density (sites outside the red circ le map, Fig. 16), *N. leisleri* was not detected on the left side of the map, while in the main study areas where forest is prevalent (inside red circle, mid) the activity of both species are present as well as in the shrubland/heather area (right side of the map). The data from the extra points on the left side of the map were unusable due to the interference on the recordings. On the day of the captures, in the main study areas no bats were detected on the

recordings of the south dots (MM10) while in the north points (MM11) *P. maderensis* (3) and *N. leisleri* (4) were detected but no bats were captured.

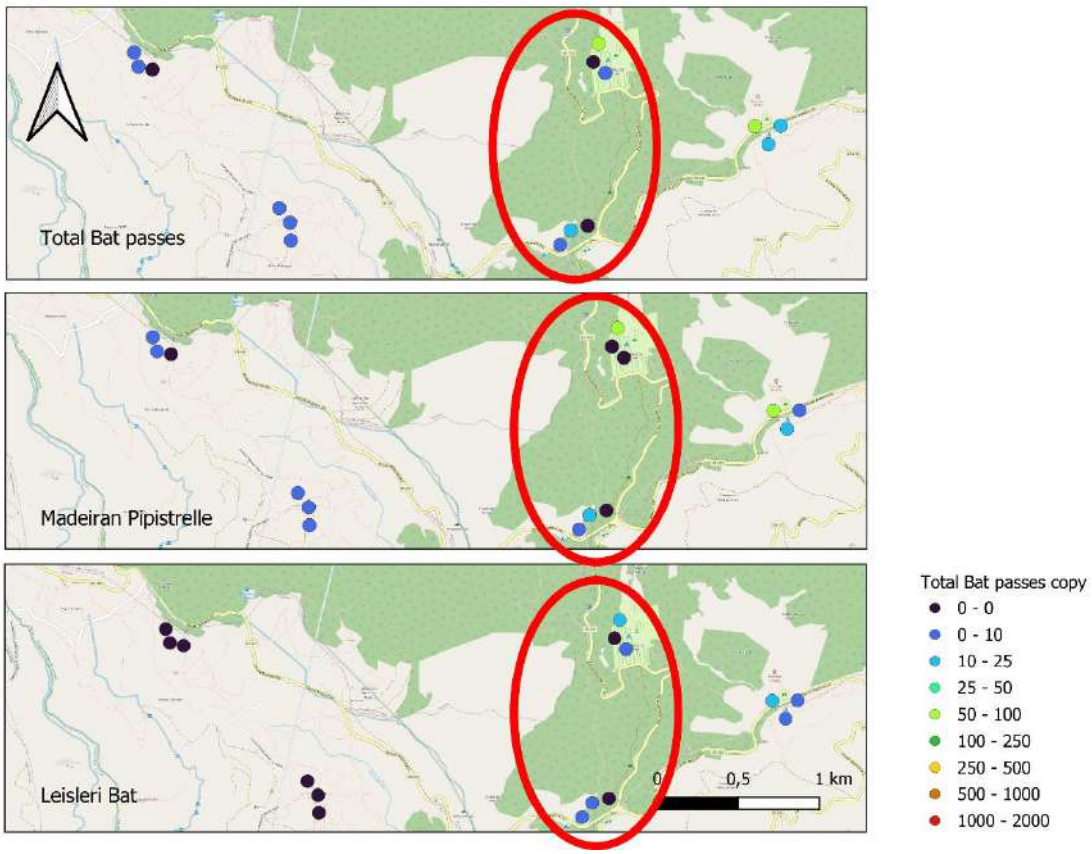


Figure 16 Number of bat passes per site on Central Mountainous areas of Madeira Island. Total Number of bat passes per site (top), Madeiran Pipistrelle (middle), Leisleri's Bat (bottom). Red circle (main areas of study).

On the east side of the island (Machico, Pico do Facho, Ponta de São Lourenço), the habitat is xeric with low vegetation with low density of introduced trees (Eucalyptus on the first two areas and Pinaceae on the last one). The bat activity appears to decrease to the east (Fig. 17).

Pipistrellus maderensis is not detected at all in Ponta de São Lourenço and only one *N. leisleri* bat pass was detected. No bats were captured or detected during the mist netting night. This is probably due to the dry area without water sources that are usually not frequented by bat populations (Fig. 17).

In Pico do Facho, the detections of bat activity seem to be closer to the route and has lower rates than Machico (left side of the map). *Pipistrellus maderensis* (41 bat passes) was detected in similar numbers as *N. leisleri* (57 bat passes) in Pico do Facho (Fig. 17). No bats were captured and both species (*P. maderensis* and *N. leisleri*) were detected using an Echometer.

On Machico area (right next to the airport of Madeira), the number of bat passes detected was high for both species. *Pipistrellus maderensis* appears to be more active towards the south area (543, 40, 6 bat passes from south to north recorder) contrary to *N. leisleri* (60, 226, 1.484 bat passes) (Fig. 17). No bats were captured, however *N. leisleri* were detected with an Echometer.

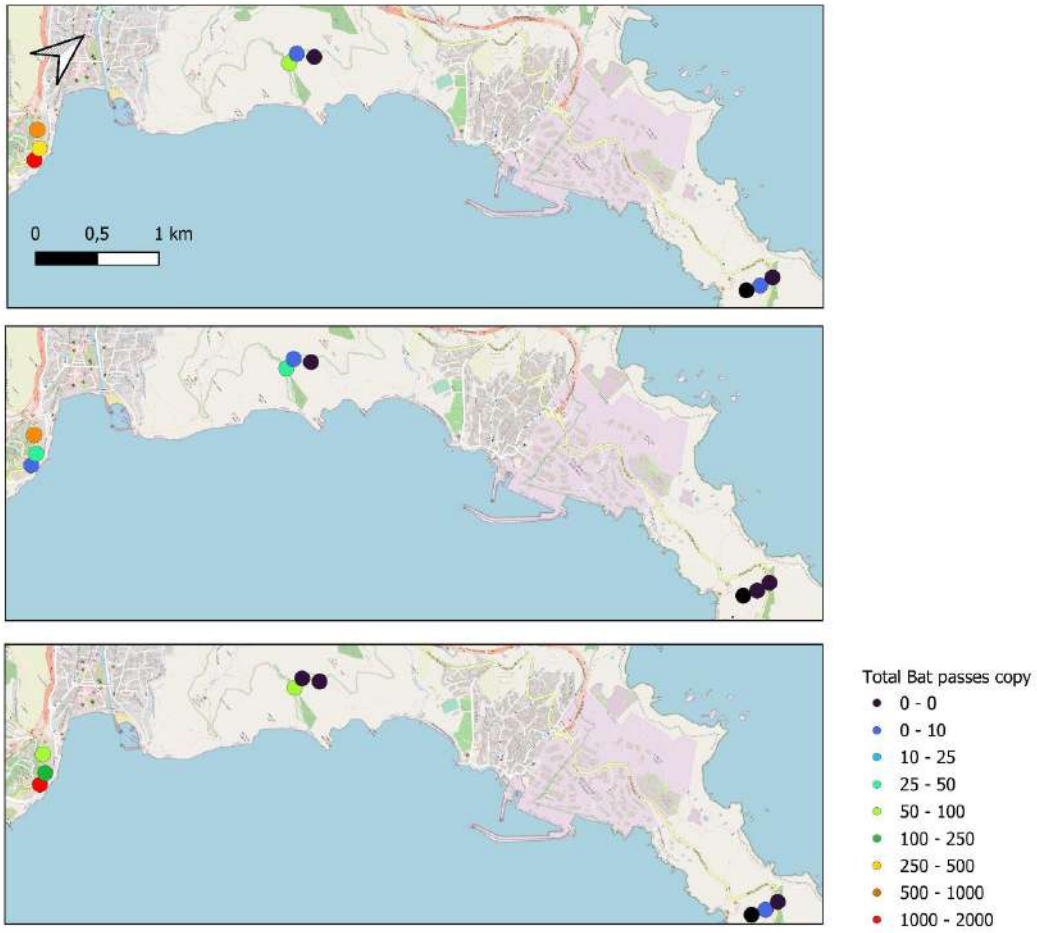


Figure 17 Number of bat passes per site on East areas of Madeira Island (Machico left, Pico do Facho middle, Ponta de São Lourenço right). Total Number of bat passes per site (top), Madeiran Pipistrelle (middle), Leisleri's Bat (bottom).

In Laurissilva Forest, the activity of *P. maderensis* is prevalent compared to *N. leisleri*. In Laurissilva, the greatest number of detections was 24 bat passes while for *P. maderensis* was 1,602 (sites 100m apart from each other in LSS7). Two captures occurred in Laurel Forest site (LSS6 and LSS7). During the captures, in LSS7 and LSS6, there were visual detections of *P. maderensis,* in LSS6 also close to the mist nets. In LSS5, no bat detections during the capture survey. In LSS8, only three bat detections (*P. maderensis*) and one *P. maderensis* detected on the LSS9 (Fig. 18).

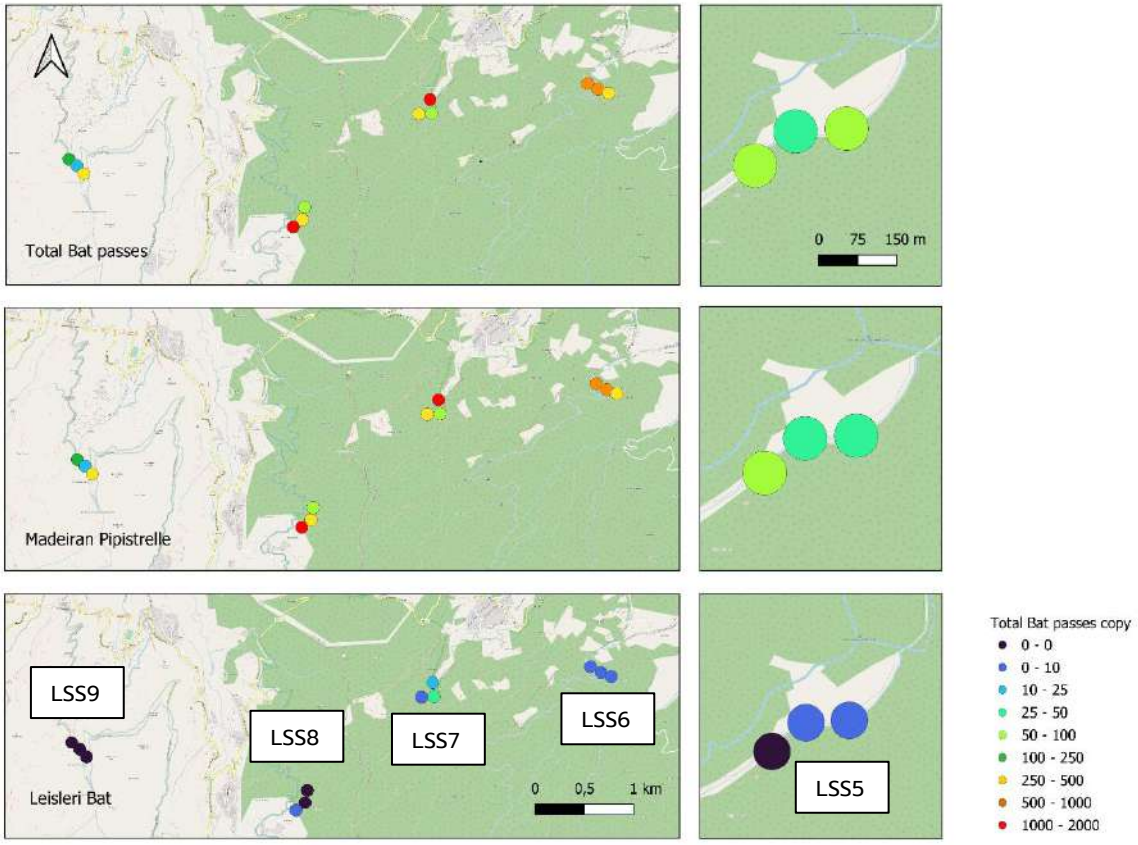


Figure 18 Number of bat passes per site on Laurissilva areas of Madeira Island. Total Number of bat passes per site (top), Madeiran Pipistrelle (middle), Leisleri's Bat (bottom).

From some extra recording sites done on the West side of the island, the greater number of bat passes from *P. maderensis* is observed in Laurissilva and mountains areas. The number of detections of the species *N. leisleri* is very low in the east Laurissilva forest (right side of the map), but high on higher altitude (on Paul da Serra, left side of the image, Fig. 19).

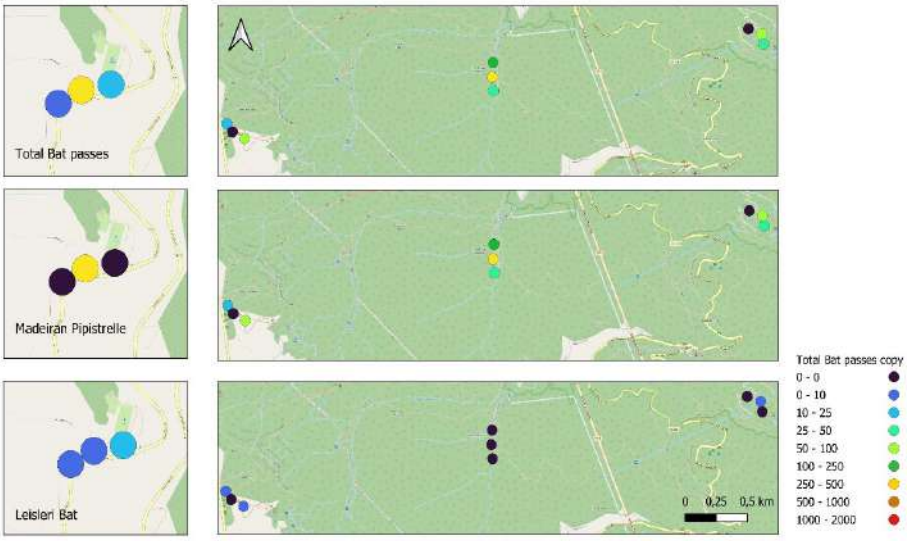


Figura 19 Number of bat passes per site on West Mountainous areas (middle dots) and Laurissilva (right and left side) of Madeira Island. Total Number of bat passes per site (top), Madeiran Pipistrelle (middle), Leisleri's Bat (bottom).

During additional observations conducted at Fajã dos Padres, beneath Cabo Girão in Câmara de Lobos, evidence indicated the presence of bats in the area (ca. 1,432 bat passes). Although both species (*P. maderensis* and *N. leisleri*) were detected, *N. leisleri* was solely detected on the second Audiomoth (the point on the right). *Pipistrellus maderensis* was identified in both recorders, 529 and 880 bat passes respectively (Fig. 20).

Figure 20 Number of bat passes per site on Fajã dos Padres, Cabo Girão in Madeira Island. Total Number of bat passes per site (left), Madeiran Pipistrelle (top right), Leisleri's Bat (bottom right).

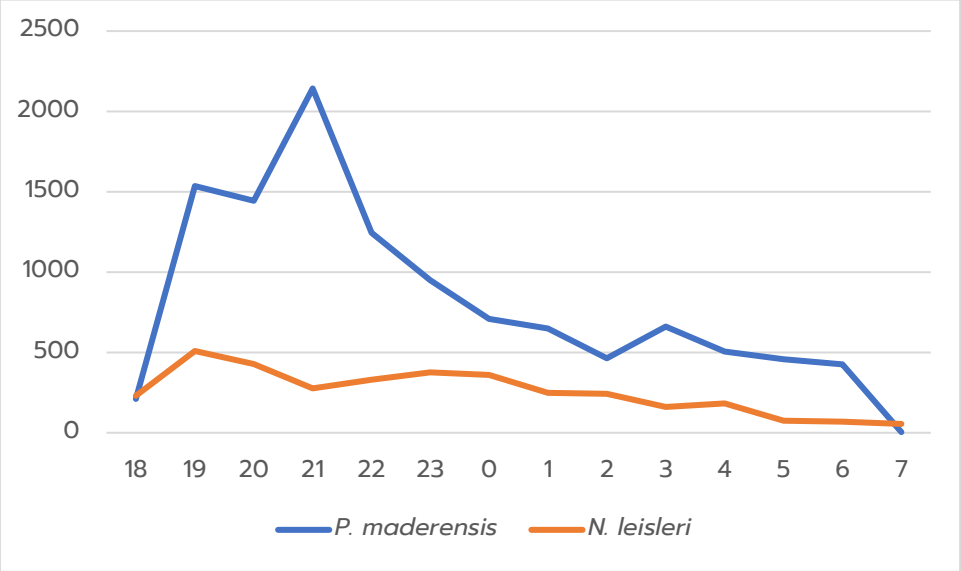


Figure 21 *Bat passes per time of the day for each of the species in Graciosa Island (N. azoreum in blue and P. maderensis in orange).*

In Madeira Island, the peak of activity of *P. maderensis* is notable at the beginning of the night. *Nyctalus leisleri* also exhibits a similar tendency to *P. maderensis* although the activity pattern is not as pronounced (Fig. 21).

3.3. Comparison of bat activity between Madeira and Azores archipelagos

By comparing the detections in Madeira and Graciosa Island, it is possible to observe that the *N. azoreum* is more frequent in Graciosa compared to *P. maderensis* (2,103 *vs* 655 bat passes). Contrary to Graciosa, on Madeira, the most common detections are *P. maderensis* (10,173 *vs* 3,263 bat passes, Fig. 22).

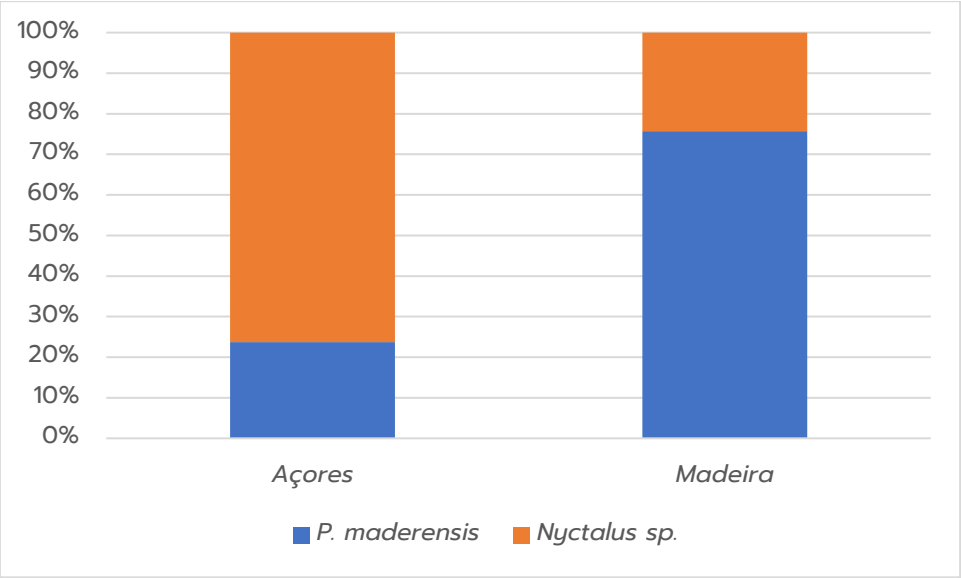


Figure 22 Percentages of *P. maderensis* and Nyctalus spp. activity in Madeira and Açores

3.4. Canaries

The data include information regarding seven native and one introduced species (table 2). The seven native species are: European free-tailed bat (*Tadarida teneotis*), Kuhli Pipistrelle (*Pipistrellus kuhlii*), Madeiran Pipistrelle (*Pipistrellus maderensis*), Savi's Pipistrelle (*Hypsugo savii*), Leisleri's bat (*Nyctalus leisleri*), Western Barbastelle (*Barbastella barbastellum*) and Canary Long-Eared bat (*Plecotus teneriffae*), and the exotic species: *Rousettus aegyptiacus*.

Tabela 2 Bats of Canaries and islands where they are present (LZ: Lanzarote; FV: Forteventura; GC: Gran Canaria; TF: Tenerife; GO: Gomera; HI: El Hierro, PL: La Palma). RPE: Special Protection Regime, PE: Special Protection, VU: Vulnerable.

Species	Family	LZ	FV	GC	TF	GO	HI	PL	Directiva Hábitat	Catálogo Nacional	Catálogo Regional
Barbastella barbastellus guanchae	Vespertilionidae				X	X			Anexo II y IV	RPE	PE
Hypsugo savii	Vespertilionidae		X	X	X	X	X	X	Anexo IV	RPE	PE
Nyctalus leisleri	Vespertilionidae				X			X	Anexo IV	RPE	PE
Pipistrellus kuhlii	Vespertilionidae	X	X	X	X				Anexo IV	RPE	PE
Pipistrellus maderensis	Vespertilionidae				X	X	X	X	Anexo IV	RPE	PE
Plecotus teneriffae	Vespertilionidae				X		X	X	Anexo IV	VU	VU
Rousettus aegyptiacus	Pteropodidae				X						
Tadarida teniotis	Molossidae			X	X	X	X	X	Anexo IV	RPE	PE

According to the data of the map shapes, bats are found in all islands from the archipelago except for Lanzarote Island. In Fuerteventura, the only species found in

the data is *P. kuhlii*. The species is found in different areas of the island including in the protected areas (Fig. 23). The species in the island is smaller than the continental species with extensive distribution in the island, being mentioned for the first time in 1922 (Trujillo, 2012). It is important to note that the two islands are the closest to the African continent and present more arid environmental conditions, scarce vegetation and not many natural water points, as well as being more exposed to prevailing winds than the other islands.

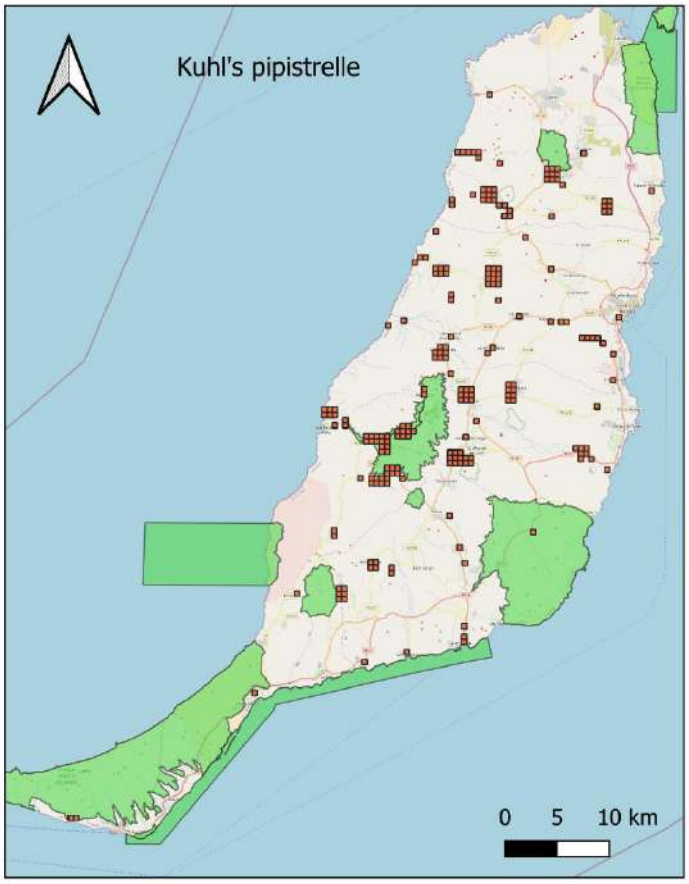


Figure 23 Kuhl's Pipistrelle in Fuerteventura. ZPE areas in green

In Gran Canary, three species were detected: *Tadarida teniotis, Pipistrellus kuhli* and *Hypsugo savii*. Some areas of the island two species were found (*P. kuhlii* or/and *T. teniotis* and *H. savii*). *Hypsugo savii* appears to have the widest distribution throughout the island. On the other hand, *P.kuhlii* and *T. teniotis* were detected in smaller areas and did not coincide on site areas. Most detections of the species were detected in the protected areas of Gran Canary (Fig. 24). According to the Trujillo et al. (2012), the population of *H. savii* appears to be recovering during the last century in the island and has a great distribution in the island. *Tadarida teniotis* and *P. kuhlii* have a very restricted distribution in the area and no recent detections in the island, respectively.

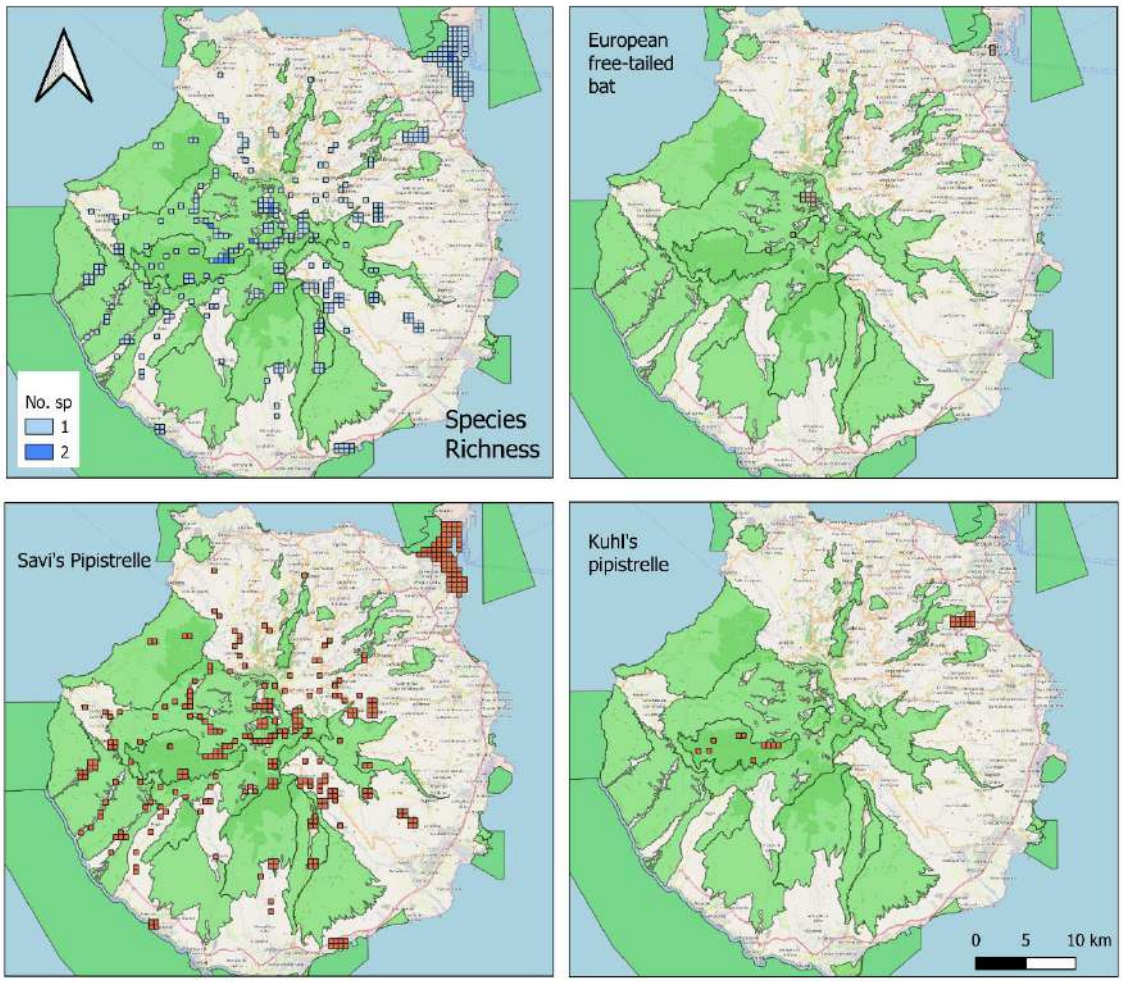


Figure 24 Bat species detected in Gran Canaria. Species richness per site (top left), Detections of European Free-tail bat (top right), Detections of Savi's Pipistrelle (bottom left), Detections of Kuhl's Pipistrelle (bottom right). Green areas represent the ZPE protected areas.

Tenerife is the island where most species described for the archipelago were detected. All the species mentioned before were detected in the data but previous data on the exotic species, escaped from zoos, have been discarded. Two sites recorded six species in the area and five sites recorded five species. *Pipistrellus maderensis, T. teniotis* and *P. teneriffae* were the species with the widest distribution in the island. *Pipistrellus kuhlii* was the species with the smallest distribution on the island. Most species seem to be detected the most in the north side of the island, however *P. kuhlii* were only detected in the middle of the island. Except for *P. maderensis* and *T. teniotis,* most species were mostly detected in the protected areas while these two species were more generally distributed across the island (Fig. 25). Recent studies that looked into the occupancy of the *P. teneriffae* in multiple islands of the Canary Archipelago finding at ca. 13 occupied caves in the Tenerife Island and 23 individuals captured (Trujillo, 2016). During the same study, a few

individuals of *P. maderensis H. savii, N. leisleri, B. barbastellus* and *T. teniotis* were also captured or recorded in the island.

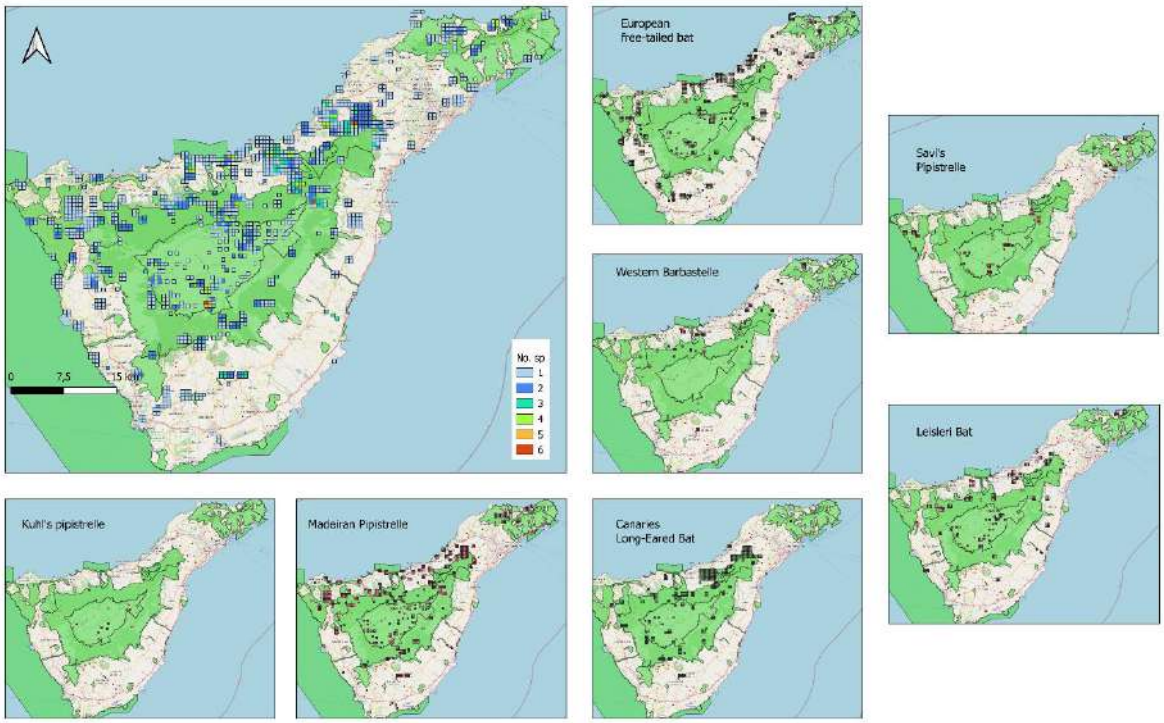


***Figure* 25** Bat species detected in Tenerife. Species richness per site (top left).

In La Gomera, four species of bats were detected: *P. maderensis, H. savii, T. teniotis* and *B. barbastellus*. In three locations, the four species were detected. *Pipistrellus maderensis* and *T. teniotis* were the species with the widest distribution across the island while *B. barbastellus* was the species with smallest distribution. The most common species were widely distributed across the protected and unprotected areas while *B. barbastellus* and *H. savii* appear to be more concentrated on the protected areas of the La Gomera island (Fig. 26). Recent research on the population status of the *B. barbastellus* in La Gomera and Tenerife but no individuals of the species was found in this little island, however some feces of the species were found (Trujillo, 2018). During the same study, a few individuals of *P. maderensis H. savii,* and *T. teniotis* were also captured or recorded in the island.

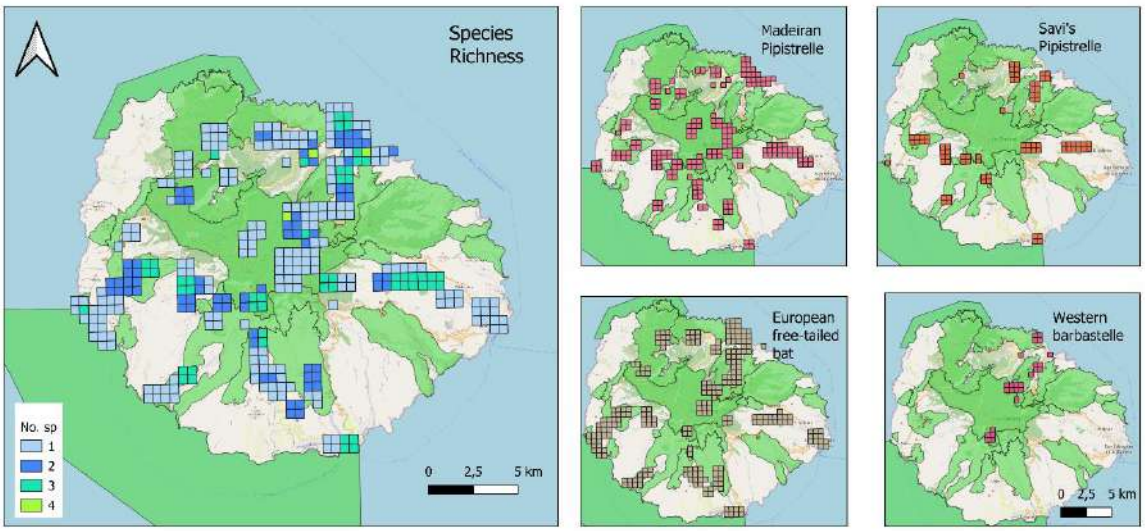


Figure 26 Bat species detected in La Gomera. Species richness per site (left), Detections of Madeiran Pipistrelle (Middle top), Detections of European Free-tail bat (bottom middle), Detections of Savi's Pipistrelle (top right), Detections of Western Barbastelle (bottom right). Green areas represent the ZPE protected areas.

In La Palma Island, five species of bats were detected: *H. savii, N. leisleri, T. teniotis, P. maderensis* and *P. teneriffae*. According to the data, *T. teniotis* appears to have the widest distribution in the island followed by *P. maderensis* and *P. teneriffae*. *Tadarida teniotis* and *N. leisleri* appear to be mostly detected outside of the protected areas while *P. teneriffae* appears to be equally detected inside and out of the protected areas. Meanwhile, *H. savii* and *P. maderensis* appear to be mostly detected in the protected areas of the La Palma Island (Fig. 27). In the most recent study researching the cave occupancy of the *P. teneriffae* in the islands, the species was found in ca. 7 occupied caves in the La Palma Island and six individuals studied (Trujillo, 2016). Also, *P. maderensis* and *H. savi* were also detected in this research.

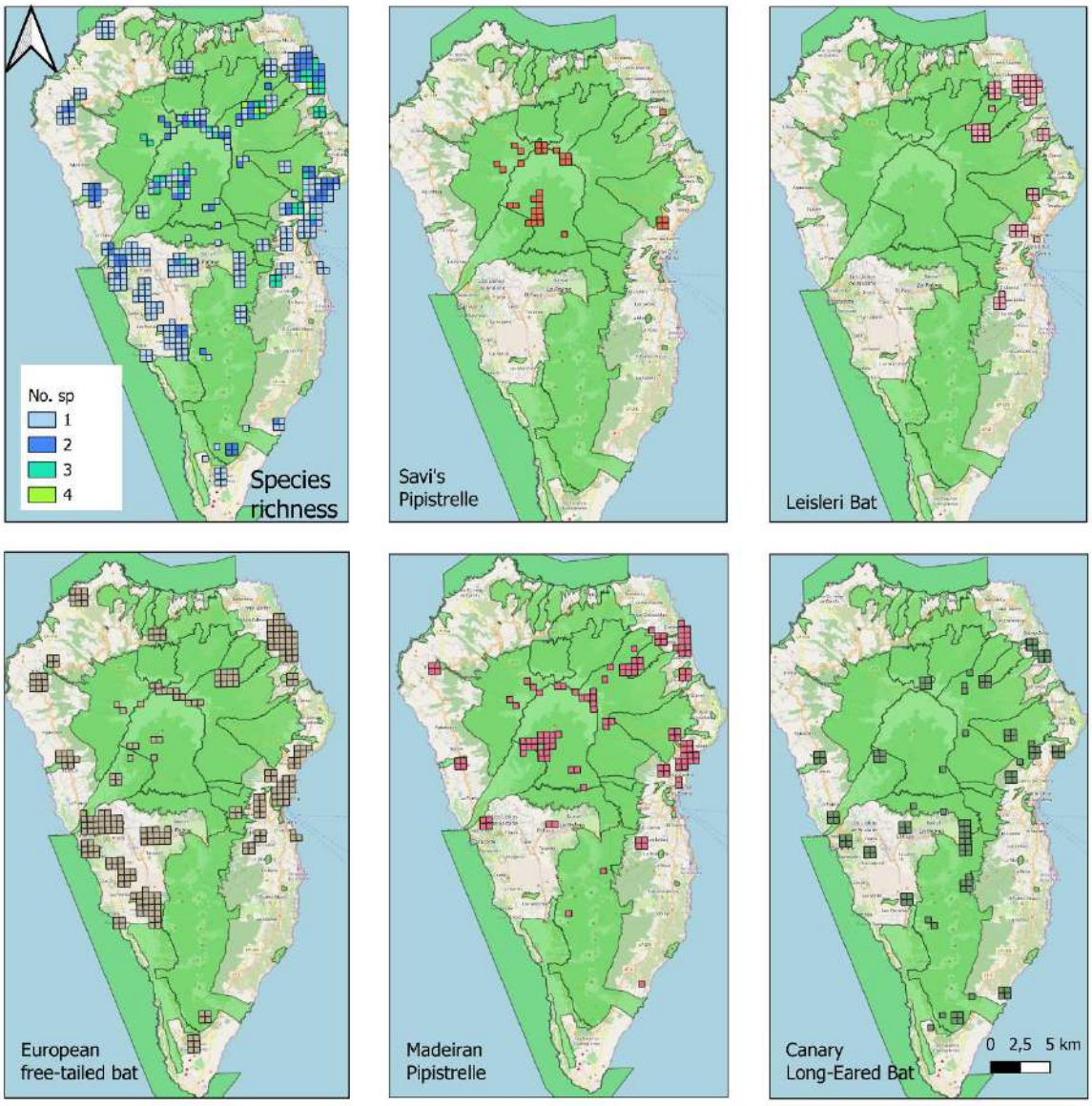


Figure 27 Bat species detected in La Palma. Species richness per site (Top left), Detections of Savi's Pipistrelle (top middle), Detections of Leisleri's bat (top right), Detections of European Free-tail bat (bottom left), Detections of Madeiran Pipistrelle (bottom middle), Detections of Canary Long-Eared Bat (bottom right). Green areas represent the ZPE protected areas.

El Hierro Island harbours four species of bats: *H. savii, P. maderensis, T. teniotis* and *P. teneriffae. Tadarida teniotis* was the species with the widest distribution in the island with a distribution mostly outside of the protected areas. *Plecotus teneriffae* and *P. maderensis* appear to be mostly detected in the protected areas of the island (Fig. 26). Trujillo et al. (2016) researched the cave occupancy of the *P. teneriffae* in the Canary Archipelago and reported 11 caves with the species in El Hierro (63 individuals captured). During this research, a few exemplars of *H. savii,* and *T. teniotis* were detected in the island.

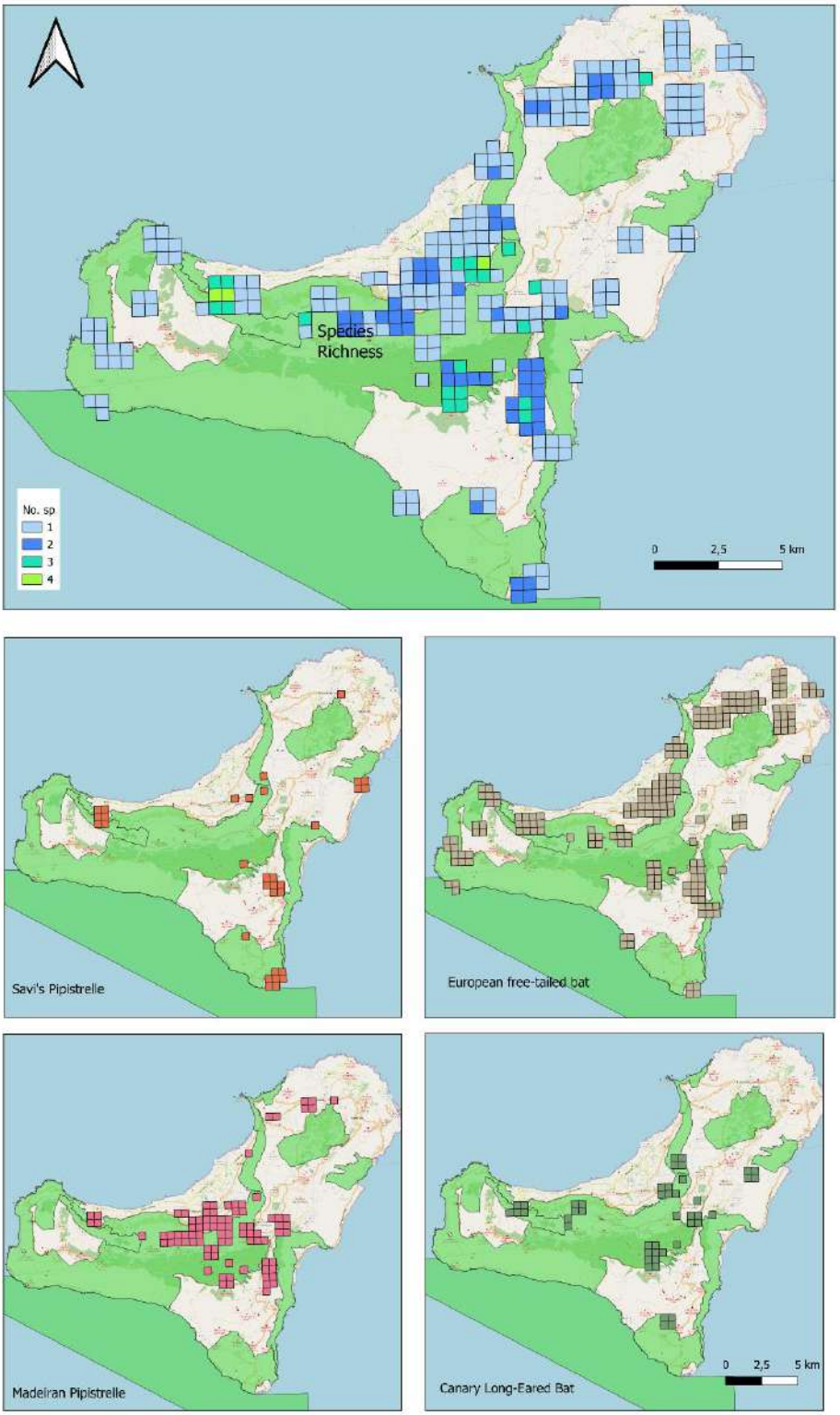


Figure 28 Bat species detected in El Hierro. Species richness per site (Top), Detections of Savi's Pipistrelle (middle left), Detections of European Free-tail bat (middle right), Detections of Madeiran Pipistrelle (bottom left), Detections of Canary Long-Eared Bat (bottom right). Green areas represent the ZPE protected areas.

4. DISCUSSION

In Macaronesia, the knowledge on bat populations has increased recently, however many aspects remain largely unknown. We studied the bat populations in the different types of habitats and Natura 2000 areas and bat populations in the three archipelagos.

Comparing the results between Natura 2000 areas on Madeira Island and Graciosa Island proved to be challenging due to their stark differences in composition and species. However, a key finding was that the prevalent species differed between archipelagos. In Azores, the most common species is *Nyctalus azoreum* across the island, while in Madeira Island it was *P. maderensis*. In the case of the Canaries, *T. teniotis* appears to be the species with the largest distribution -perhaps because it is more easily audible- followed by *P. maderensis*. Unfortunately, data regarding bat activity in the Canaries was not available for comparison with the other islands.

Pipistrellus maderensis is strongly associated with forest areas (especially Laurel Forest, Ferreira et al., 2021). The bioacoustic analysis shows that in Madeira Island the species is detected most frequently in the Laurel Forest areas and in the south area of the island (coastal areas). Conversely, in Graciosa Island, the species was mostly detected in the Caldeira (N2000) and might be associated mostly with urban areas and forest areas, however more analysis are needed to detail the habitat preferences.

Nyctalus leisleri, in Madeira Island, appears to be mostly associated to the coastal areas in both sides of the island including Machico in the east side of the island. The species had lower activity in the Laurel Forest in the north side of the island and mountainous areas of the island. In Graciosa Island, the species was very active in two out of the locations in the N2000 areas (Farol do Carapacho and Caldeira). Overall, in the island, the species was mostly distributed in the northeast areas of the island.

According to Rainho et al. (2021), *N. azoreum* seems to be mostly associated to larger islands while *P. maderensis* is mostly associated to smaller islands in Azores. Graciosa Island is the second smallest island in Azores and the prevalent species during our survey was *N. azoreum.* The species is highly associated to streetlights and water areas where they forage while *P. maderensis* is mostly associated to green areas on

low altitude coastal areas. The diurnal activity of *N. azoreum* is also an important factor to consider in these analyses.

Unfortunately, in Madeira Island no *Plecotus austriacus* were detected probably due to the difficulty to detect. Further analysis is necessary to understand the populations of bats in the different Natura 2000 and more data will be necessary to compare the populations from the Canaries with the other archipelagos. However, the data collected might be relevant to verify the effects of the streetlight changes in the Natura 2000 areas.

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ANNEXES

A – Research Data used for the bat analysis in Canaries from Banco de Datos de Biodiversidad de Canarias

Code	*Autor*	*Year*	*Title*	*Precision*	*Confidence*
D00330	Cruz, T., Cruz, A.	2003	Inventario ambiental. Avance de planeamiento. Plan especial de ordenación del litoral Punta del Hidalgo (T. M. La Laguna, Tenerife).	2	Secure
D00668		2009	Inventario de fauna vertebrada en: Memoria 2009 Parque Nacional del Teide.	1	Secure
D00696	Trujillo, D.	2011	Nuevas citas de murciélago rabudo Tadarida teniotis (Rafinesque, 1814) en Gran Canaria, islas Canarias (Chiroptera, Molossidae).	1	Secure
D00807	Fajardo González, S.	2011	Informe sobre la presencia de quirópteros en la Reserva Natural Integral de Inagua - ZEC-GC 45.	1	Secure
D00841	Trujillo, D.	2012	Seguimiento de poblaciones insulares de murciélagos en Gran canaria y Fuerteventura y de Plecotus teneriffae en cavidades volcánicas de La Palma.	1	Secure
D00844	Trujillo, D., Barone Tosco, R., García, D.	2012	Estatus y distribución del murciélago montañero Hypsuto savii (Bonaparte, 1837) en Gran Canaria, islas Canarias (Chiroptera: Vespertilionidae).	2	Secure
D00878	Trujillo, D.	2011	Estado de las poblaciones de quirópteros en el Parque Nacional de La Caldera de Taburiente (años 2010-11).	1	Secure
D01188	Trujillo, D.	2014	Datos inéditos cedidos por D. Trujillo para el Banco de Datos de Biodiversidad de Canarias.	1	Secure
D01257	Fajardo González, S.	2013	Recopilación de formularios para el registro de datos inéditos de distribución de especies terrestres cedido por Silvia Fajardo González	1	Secure
D01258	Fajardo González, S.	2014	Recopilación de formularios para el registro de datos inéditos de distribución de especies terrestres cedido por Silvia Fajardo González	1	Secure
D01477	Trujillo, D.	2014	Informe sobre la situación de la población del murciélago egipcio (Rousettus aegyptiacus) en Tenerife.	1	Secure
D01734	Fajardo González, S.	2015	Datos inéditos cedidos por Silvia Fajardo para el Banco de Datos de Biodiversidad de Canarias.	1	Secure
D02532	Benzal, J., Izquierdo, I.	1993	Programa de protección y conservación de murciélagos. (Informe de 1993).	1	Secure
D02533	Benzal, J., Fajardo González, S.	1994	Programa para la protección y conservación de los murciélagos. (Informe de la campaña de 1994).	2	Secure
D02534	Fajardo González, S.	1995	Programa para la protección y conservación de los murciélagos de Canarias. (Informe de la campaña de 1995).	2	Secure
D03196	Trujillo, D.	2018	Estudio de la distribución, hábitat y estado de conservación del murciélago de bosque canario (Barbastella barbastellus guanchae). Cofinanciado por el Programa Operativo Feder Canarias (2014-2020).	1	Secure
D03197	Trujillo, D.	2016	Seguimiento de las poblaciones de orejudo canario (Plecotus teneriffae) y sus refugios en cuevas de La Palma, El Hierro y Tenerife. Informe inédito. Gobierno de Canarias.	1	Secure
F00069	Brito, M. C., Lucía Sauquillo, V.	1995	Espacios Naturales de Tenerife. El Bosque de Agua García	2	Secure
P00013	Trujillo, D.	2014	Informe sobre la situación de la población del murciélago egipcio (Rousettus aegyptiacus) en Tenerife.	1	Secure
P00400	Domínguez-Yanes, J.F.,	2019	Censo de quirópteros de los parques eólicos de Vera de Abote y Bermejo (Término Municipal de Arico, Tenerife, Islas Canarias).	1	Secure

	Mateos-Calvo, A.				
P00773	González-Dionis, J., Castillo Ruiz, C., Cruzado-Caballero, P., Cadavid-Melero, E., Crespo, D.	2021	First study of the bat fossil record of the mid-Atlantic volcanic islands.	1	Secure
P00853	Fajardo González, S.	2022	Datos inéditos cedidos por Silvia Fajardo para el Banco de Datos de Biodiversidad de Canarias (2022).	1	Secure
P00930	Fajardo González, S., de Felipe Delgado, E.	2022	Datos inéditos de Barbastella barbastellus guanchae cedidos por Silvia Fajardo González y Edgar de Felipe Delgado para el Banco de Datos de Biodiversidad de Canarias (2022).	1	Secure
P01326	Fajardo González, S.	2022	Datos inéditos cedidos por Silvia Fajardo para el Banco de Datos de Biodiversidad de Canarias.	1	Secure
V00004	Fajardo González, S., García, L., Benzal, J.	2001	El patrón de distribución del murciélago de bosque (Barbastella barbastellus) en España y la posible influencia de su especificidad alimentaria.	2	Dudoso
V00079	Barret-Hamilton, G. E. H.	1907	Descriptions of two new species of Plecotus.	2	Secure
V00133	Fajardo González, S.	1996	Programa para la Protección y Conservación de los Murciélagos, 1996.	1	Secure
V00134	Bannerman, D. A.	1922	The Canary Islands. Their History, Natural History and Scenery. An account of an ornitologist`s camping trips in the archipielago.	2	Secure
V00150	Tomes, R. F.	1859	Description of six hitherto undescribed species of bats.	4	Secure
V00213	Hutterer, R.	1979	Occurence of the European free-tailed bat Tadarida teniotis on Hierro, Canary Islands.	2	Secure
V00230	Trujillo, D.	1991	Murciélagos de las islas Canarias.	2	Secure
V00236	Hutterer, R.	1989	Distribution of Tadarida teniotis in the Canary Islands.	2	Secure
V00267	Bannerman, D. A.	1914	An ornithological expedition to the eastern Canary Islands. Part I - II.	2	Secure
V00323	Trujillo, D.	2000	Quirópteros anillados en las Islas Canarias durante 2000.	1	Secure
V00399	Pestano, J., Brown, R. P., Suárez, N. M., Fajardo González, S.	2003	Phylogeography of pipistrelle-like bats within the Canary Islands, based on mtDNA sequences.	1	Secure
V00420	Fajardo González, S., Benzal, J.	2002	Datos sobre la distribución de quirópteros en Canarias (Mammalia, Chiroptera).	1	Secure
V00440	Fajardo González, S.	1998	Programa para la protección y conservación de los murciélagos de Canarias.	2	Secure
V00502	Fariña, B., Arechavaleta, M.	2003	Gallotia galloti insulanagae Martín. Tenerife. Seguimiento de Poblaciones de Especies Amenazadas 2003.	1	Dudoso
V00535	Fajardo González, S.	2001	Conservación de Quirópteros e Invertebrados en Cavidades Volcánicas.	1	Secure
V00593		2007	Base de datos del Centro de Recuperación de Fauna Silvestre "La Tahonilla". Especies protegidas de Vertebrados	2	Secure