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Deliverable - Review on the effects of ALAN in bats in with special focus on the Macaronesia Region

Funchal, March, 2023

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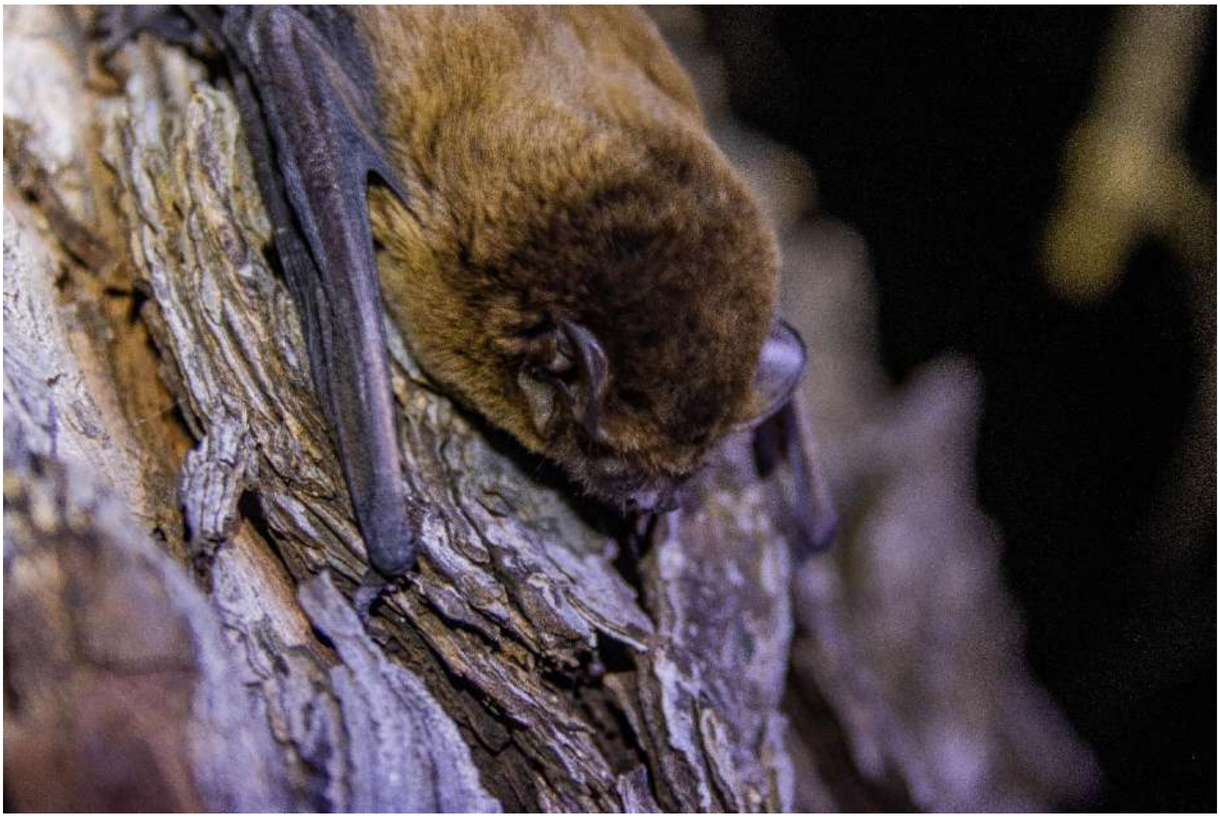

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No projeto **LIFE Natura@Night**, pretendemos a redução e mitigação do impacte da poluição luminosa nas áreas de Rede Natura 2000 da Macaronésia.

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Deliverable - Review on the effects of ALAN in bats in with special focus on the Macaronesia Region

Sociedade Portuguesa para o Estudo das Aves, 2023

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ÍNDICE

SUMMARY

Bats are an incredibly diverse group of mammals and play a variety of important roles in the ecosystems. Insectivorous species are crucial for controlling insect populations, including disease vectors and agriculture pests. Unfortunately, bats face a variety of threats, one of which is the negative impact of artificial light at night (ALAN). Streetlights affect the foraging activity of the bats in various ways, depending on the species, habitat, and other factors. Mitigation methods for ALAN have been developed and tested, but little research has been done in island bat populations. Given the importance of bats for the maintenance of the ecosystems, it is crucial to study more the impacts of ALAN on bat populations and the mitigation process.

1. INTRODUCTION

Bats are second largest group of mammals, comprising about one fifth of all mammalian diversity worldwide, with over 1,430 species (Simmons et al., 2021). This group of animals display a wide diversity of dietary patterns, foraging behaviour, roosting ecology, and habitat use (Patterson et al., 2003, Altringham, 2011). They occur on every continent except in the polar regions and provide numerous ecosystem services, such as pest control, seed dispersal, and pollination, making them potential bioindicators (Jones et al., 2009a; Kunz et al., 2011; Ramírez-Fráncel et al., 2022). Insectivorous bats play crucial roles in controlling arthropod populations which may result in a reduced pesticide demand in agriculture thus preventing substantial economic losses, e.g. 1 billion USD in corn production in USA and 1.2 million USA in rice fields in Thailand (Kurta et al., 1989; Kunz et al., 1995; Kunz et al., 2011; Kolkert et al., 2019, Puig-Montserrat et al., 2015, Puig-Montserrat et al., 2020; Maine and Boyles, 2015, Wanger et al. 2014; Ramírez-Fráncel et al., 2022). They also aid in disease vector control, potentially benefiting human and domestic animal's health (Kemp et al., 2019; Ghanem & Voigt 2012; Ancillotto et al., 2021).

However, according to the IUCN Red List, ca. 15% of bat species are currently threatened, and ca. 18% are classified as Data Deficient (Frick et al., 2020). Deforestation and agriculture result in a loss and fragmentation of habitat, limiting foraging and roosting resources for many species (Rocha et al., 2017a; Williams-Guillén et al., 2016). Insecticides used in agriculture are also a direct threat to insectivorous species (Williams-Guillén et al., 2016). Additionally, cultural beliefs, climate change and invasive species, are significant concerns (Welch & Leppanen, 2017; Frick et al., 2020; Festa et al., 2022). Recent studies have shown significant impacts of artificial light at night (ALAN) on bat's foraging behaviour; however, this threat is still limited in the IUCN assessments in the threats to bat populations (Frick et al., 2020)

Bats tend to be great colonizers of oceanic islands due to their flight capacity, and often represent most of the native terrestrial mammals in these islands. About 60% of all bat species are found on islands and ca. 25% are endemic to islands (Jones et al., 2009b; Conenna et al., 2017). However, insular bats are relatively poorly studied, despite inhabiting some of the world's most vulnerable habitats due to its isolation (Conenna et al., 2017). About 50% of insular bat species are threatened, and five out of all island endemics have gone extinct (Jones et al. 2009b, Conenna et al. 2017, IUCN 2018). Island species are more susceptible to threats caused by human actions, intrinsic factors, and extrinsic factors such as natural disasters, when compared to species with a widespread distribution. The extinction and decline of island bats populations may result in a loss of important ecological services on the islands where they occur (Fleming & Racey, 2009; Conenna et al., 2017), increasing the urgency the study and mitigation of their possible threats, such as ALAN.

2. METHODOLOGY

Between September 2022 and January 2023, we conducted bibliographical research on the species, distribution, and abundance of nocturnal Chiroptera in Macaronesia (1), the effects of Artificial Light at Night (ALAN) on bats (2), and best practices for street lighting to mitigate such effects (3). To search for relevant literature, we used Google Scholar and selected the following keywords: "Bat," "Macaronesia," "Azores," "Canary Islands," "Canaries," and "Madeira" (1); "Artificial light," "Effect," "Bat," "Insectivorous" (2, 3). In total, we included 190 publications from our initial research process (1: 94; 2 and 3: 96). All publications that contained valuable information and were written in English, Portuguese, or Spanish were included. For topics 2 and 3, we mainly included articles published after 2016 added to the information read on the review of 2015, Stone et al. (2015). During the first phase of screening, we analysed the titles and abstracts and included all articles related to bats from Macaronesia (1) and all articles that mentioned artificial light and bats (2 and 3) in the review. We complemented the review with books and did include ca. 6 theses/reports. In total, we used ca. 112 publications, and we also identified additional relevant publications by analysing the bibliographies of the selected articles.

Macaronesian Bats (1)

We conducted a detailed analysis of the research articles based on location, field of study (e.g., biology, genetic, conservation, land-use), and the species studied. Our focus was directed to research papers that studied the species in the islands of Macaronesia and made comparisons across the different species, archipelagos and islands.

Effects of ALAN on Bats and Mitigation of its effects (2 and 3)

Our analysis focused on an examination of research articles considering study location and habitat, main topic (e.g., light effect, light colour, light change, urbanization effect), type of light (artificial or moonlight), species studied, impact of the light on bats, experiment (e.g. type of lamp used, light intensity, light colour), and information on mitigation of ALAN. The research papers consulted focused mainly on bat populations and were published after 2015, which investigated the effects of ALAN on bats with special focus on the genus/species present in Macaronesia.

3. Chapter I: Macaronesian Bats

3.1. Macaronesia

Macaronesia is a biogeographical region with four archipelagos located in the Atlantic Ocean between SW Europe and NW Africa. The region has a total of 39 islands larger than 1 km², hundreds of islets and rocks of smaller size. The archipelagos belong to different countries, such as Portugal (Azores and Madeira), Spain (Canaries), and Cape Verde (Masseti., 2010).
This biogeographical region has an outstanding biodiversity with numerous endemic species and wide array of adaptive radiation (Whittaker & Fernández-Palacios 2007; Brilhante et al. 2021, Florencio et al. 2021). Macaronesia is characterized by the reduced number of native terrestrial mammal species including ca. 16 species of bats (Masseti., 2010). The different archipelagos have different types of climates associated to latitudinal differences. The dominant climate in Madeira and the Canaries is Mediterranean, while the Azores has an oceanic temperate climate. Cape Verde is characterized by a dry climate and tropical

monsoon during summer. There are three main factors that affect the rainfall gradients in the region: a latitudinal gradient (decreasing precipitation from Azores to Cape Verde), a longitudinal gradient (increasing precipitation from the localities nearer to the continent towards those located farther on all archipelagos), and an altitudinal gradient (increasing precipitation in every island from the coast to the island's peaks) (Fernández-Palacios, 2011).

Table 1 *Compilation of the bat species in Macaronesia*

Species	Island	Archipelago
Barbastella barbastellus guanchae	Tenerife	Canary
	La Gomera	
Eidolon helvum		Cape Verde
Hypsugo savii	La Palma	Canary
	El Hiero	
	La Gomera	
	Tenerife	
	Gran Canaria	
	Fuerteventura	
	Fogo	Cape Verde
	Brava	
	S. Nicolau	
	S. Vicente	
	S. Antão	
Miniopterus schreibersii	S. Antão	Cape Verde
Myotis myotis	Graciosa	Azores
Nyctalus azoreum	S. Jorge	Azores
	St. Maria	
	S. Miguel	
	Graciosa	
	Faial	
	Pico	
	Terceira	
Nyctalus leisleri	La Palma	Canary
	Tenerife	
	Lanzarote	
Nyctalus leisleri ssp. Verrucosus	Madeira	Madeira
Pipistrellus kuhlii	Tenerife	Canary
	Gran Canaria	
	Fuerteventura	
	Lanzarote	
	S. Vicente	Cape Verde
	S. Nicolau	
	Fogo	
	Santiago	
Pipistrellus maderensis	St. Maria	Azores

	Graciosa	
	Corvo	
	Flores	
	S. Jorge	
	Madeira	Madeira
	Porto Santo	
	La Palma	Canary
	La Gomera	
	El Hierro	
	Tenererife	
***Pipistrellus* sp.**	Pico	Azores
Plecotus austriacus	Madeira	Madeira
	Maio	Cape Verde
	Santiago	
Plecotus teneriffae	Tenerife	Canary
	La Palma	
	El Hierro	
	La Gomera	
Tadarida teniotis	La Palma	Canary
	Tenerife	
	El Hiero	
	La Gomera	
Taphozous nudiventris	Maio	Cape Verde
	Santiago	

3.2. Azores Archipelago

The Azores archipelago is part of Portugal, located 1.400 km west of the coast, comprises of nine volcanic islands and some small islets (Rainho et al., 2002). Due to its proximity to a triple plate junction (North American, Eurasian and African plates), the archipelago experiences active volcanic activity (Cruz et al., 2006). The archipelago's maximum altitude ranges vary between islands from ca. 400 to 2,350 m, several islands with altitudes higher than 1,000 m (Silva et al., 2004). The region's original Azorean Forest was characterized by a native laurel forest, but human activities like forest industry, cultivation, and pastures have significantly altered the landscape (Rainho et al., 2002; Elias et al., 2016).

In the archipelago, a rich diversity of fungus, plants and animals including many endemic species and subspecies can be found (Ferreira et al., 2016). Among the mammalian population, bats appear to be the only native group that currently exists (Rainho et al., 2002). In Azores, two species have been confirmed (*Nyctalus azoreum* and *Pipistrellus maderensis*) and the presence of three species remains unclear (*Myotis myotis*, *Pipistrellus pipistrellus*, an unknown *Pipistrellus* in S. Jorge, Table 1) (Lopes, et al., 2011; ICN, 2002; Mathias, 1998). According to some studies, the main species found in Azores (*N. azoreum* and *P. maderensis*) have a specific distribution related to the island size or level of isolation (larger and smaller islands respectively) (Rainho, et al., 2022). Both confirmed species (N. azoreum and P. maderensis) are classified as vulnerable by the IUCN Red List due to its isolation and small distribution.

3.3. Madeira Archipelago

The Madeira archipelago is a region of Portugal located in the North Atlantic Ocean, southwest of the Iberian Peninsula. The archipelago, which is of volcanic origin, includes two inhabited islands (Madeira and Porto Santo) and two smaller island groups (Desertas and Selvagens). The archipelago is located at approximately 700 km from Africa and 980 km from the Iberian coast. Madeira island is distinguished by its mountainous terrain, with Pico Ruivo as its highest peak (ca. 1,862 m altitude). The prevailing north-easterly winds result in several different microclimates on the island, resulting in a great variety of ecosystems (Delgado et al., 2006).

The great variety of microhabitats in the archipelago has resulted on a huge diversity of native species including numerous endemic species (Delgado et al., 2006). The terrestrial mammalian fauna of the archipelago is poor in terms of species richness, and apart from bats, all terrestrial mammals have been introduced. Although historical records report the occurrence of five bat species in the archipelago (*Pipistrellus maderensis, Nyctalus leisleri, Plecotus austriacus, Tadarida teniotis* and *Hypsugo savii,* Table 1), recent studies have only confirmed the presence of the first three species. The Madeira pipistrelle (*Pipistrellus maderensis)* is endemic to Macaronesia and is classified as Vulnerable by the IUCN Red List (Alcaldé et al., 2022). It is found in different types of habitats, being relatively abundant in forest, agricultural, and urban biotopes. Leisler's bat is a typical European forest bat with a diet that consists of small to medium-sized insects, often feeding near freshwater habitats. In Madeira, it is represented by the endemic subspecies *N. leisleri verrucosus*. *Plecotus austriacus* is an European long-eared bat that arrived in Madeira during its westward expansion across Europe. Its diet primarily consists of moths, but other insect taxa are also part of its diet. It forages mostly on open-edge habitats and is a sedentary species.

3.4. Canary Archipelago

The Canary Archipelago is a group of seven volcanic islands and numerous islets situated ca. 100 km northwest from African coast (Nogales et al., 2006). The islands' altitudes range from 671 m (Lanzarote) to 3,718 m (Tenerife), resulting on a wide range of vegetation types across the archipelago. The islands located closer to the east are affected by the winds of the Sahara Desert, resulting in a xerophytic climate associated with low altitudes. Meanwhile, the higher mountainous islands feature varying types of vegetation depending, including humid forest habitats (e.g., Laurel Forest) and dry monospecific pine forests found at higher elevations (Nogales et al., 2006).

Nowadays, seven native species of bats are known to the Canary Islands from the genus *Pipistrellus*, *Plecotus*, *Barbastella* and *Tadarida* (Afonso-Carrillo, 2007; Table 1). It is also believed that the insecticides used for pest control in 1950s may have impacted the bat populations on the islands. The diversity of species seems to be linked to the diversity of the habitat provided by the mountains. Bat activity is detected during all the seasons of the year on the low and mid-altitude regions (Trujillo & Barone, 1993). The main endemic species in Canaries are a Macaronesian endemic (*Pipistrellus maderensis*), one endemic subspecies to the Canaries (*Barbastella barbastella guanchae*) and an endemic species restricted to Canaries (*Plecotus teneriffae*) (Afonso-Carrillo, 2007). It is believed that in 2000, some individuals of the Egyptian bat species (*Rousettus egyptiacus*) may have escaped and subsequently established two colonies in Tenerife[1], which represents a significant environmental problem (Trujillo, 2003; Nogales et al., 2006).

3.5. Cape Verde Archipelago

The Cape Verde Archipelago has ten main volcanic islands located 570 meters from the African coast and 1,500 kilometres south from Canary Islands. The islands are characterized by an arid and semi-arid climate (Borloti et al., 2020) and have diverse ecosystems, providing opportunities for a wide range biodiversity, particularly in the mountainous terrain of the northern and southern islands (Romeiras et al., 2015; Vasconcelos et al., 2012). However, information about the archipelago's environment prior to anthropogenic changes is limited, and many introductions of species, such as green monkeys (*Chlorocebus sabaeus*), have occurred (Hazevoet & Masseti, 2011).

Like other archipelagos, Cape Verde has a reduced number of terrestrial mammal species, with bats being the only native non-marine mammals. However, few studies have been conducted, and older studies report the presence of five bat species on the archipelago, including Naked-rumped Tomb Bat (*Taphozous nudiventris*), Savi's pipistrelle (*Hypsugo savii*), Kuhl's pipistrelle (*Pipistrellus kuhlii*), Grey Long-Eared Bat (*Plecotus austriacus*), and Schreiber's Bat (*Minipterus schreibersii*) (Table 1). Information on their distribution is limited, and studies suggest that these species are rare and recent arrivals to the archipelago (Tranier & Naurois, 1985; Vasconcelos, 2018). Recent studies have verified the presence of *H. savii* and *P. kuhlii* in São Nicolau and Brava (Vasconcelos, 2018). Borloti et al. (2020) also suggests that *H. savii* population in Cape Verde is closely related to populations in the Canary Islands, highlighting the need for more phylogenetic studies of bat populations in this archipelago.

3.6. Azorean Bat (*Nyctalus azoreum* Thomas 1901)

The Azorean Bat, *Nyctalus azoreum*, was originally described as *Pterytistes azoreum* by Thomas in 1901. It is genetically similar to *N. leisleri,* suggesting that it may have evolved from the mainland species (Rainho, 2002; Dechmann & Ruczynski, 2020). It is an endemic species of the Azores and can be found on at least seven of the nine islands in the archipelago: Fail, Pico, San Jorge, Graciosa, Terceira, San Miguel and Santa Maria (Dechmann & Ruczynski, 2020). This is the smallest species of *Nyctalus* in Europe, with a body size of 54 mm, tail length of 35 mm, and weight of 15 g (Rainho, 2002; Salgueiro, 2007). Besides being smaller than *N. leisleri*, it has darker coloration and slightly lighter fur on the ventral area. Skin colour is almost black (Dechmann & Ruczynski, 2020). No data is currently available on its physiology (Dechmann & Ruczynski, 2020).

Males of the species are mainly solitary, while females and their young gather in maternity colonies from April till September or October. Females usually give birth to their young between June and July. Out of the mating season, females appear to be solitary or roost in

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[1] More data: https://www.biodiversidadcanarias.es/exos/especie/V00117

small groups (Leonardo & Medeiros, 2011). *N. azoreum* form roosts in buildings, coastal cliffs, and trees (Leonardo & Medeiros, 2011). The species forages in all available habitats, commonly in forest edges and observed close to streetlights. It is a fast flyer and forages around 25 m above the ground. It is well known for its occasional daytime foraging behaviour (Moore, 1975, Speakman & Webb, 1993, Leonardo & Medeiros, 2011).
The species has nearly CF calls with frequencies reaching between 27.3 and 32.9 kHz, with durations of about 16.8 ms. *N. azoreum* has more broadband calls with more FM elements compared to other species of noctules (Lefèvre & Barataud, 2020). Parasites and diseases associated with the species are currently unknown (Dechmann & Ruczynski, 2020). The population has been estimated have around 1,750 and 23,650 individuals based on day and night activity, respectively (Speakman & Webb, 1993). The species is fairly common in the Azores, with about ten individuals per km^2 (Speakman & Webb, 1993).
The IUCN classifies the species as Vulnerable (VU) due to its small distribution range and long-distance dispersal in the European Red List. The species is also listed in the Bern Convention Appendix IV of the EU Habitats and Species Directive. The main threats to the species are the destruction of roost sites, habitat loss, the use of pesticides, and the spread of exotic plants. The fact that the species is active during the day makes it easy to find the colonies, making it particularly vulnerable (IUCN, 2016).

3.7. Madeiran Pipistrelle (*Pipistrellus maderensis,* Dobson 1878)

The species was first described by Dobson in 1878 as *Vesperugo maderensis*. *Pipistrellus maderensis* is morphologically and genetically similar to *Pipistrellus kuhlii*. Recent studies suggest that *P. maderensis* evolved from African *P. kuhlii* (Pestana, 2003; Rocha, 2021). Molecular studies indicate that *P. kuhlii* may have colonized the Canary Islands twice, and the older lineage might have given rise to the Macaronesian endemic species, *P. maderensis*, during the Middle Pleistocene (Evin et al., 2011). However, no fossils of the species have been discovered. *P. maderensis* is an endemic species found in Macaronesia, being found in Madeira, Canaries, and Azores (Rocha, 2020). *Pipistrellus maderensis* is a small bat (forearm length 29.5 – 34.0 mm) with uniform chocolate-brown to orange-brown fur, with dark brown bare skin (Teixeira & Jesus, 2009; Palmeirim et al., 1999). The rounded ears are short (ca. 10 mm) and not connected at the base, with a short, rounded tragus (Rocha, 2021; Jesus, 2009). The tail is within the urapatagium and in some individuals, there is a defined white border on the free edge of the wing (Trujillo, 1993). The species has a dental formula of 2.1.2.3/3.1.2.3, with 34 teeth and the first upper incisor having only one cusp (Jesus, 2009; Rocha, 2020). Phylogenetic studies using mtDNA suggest the existence of at least four lineages of the species in terms of diversity, with three in the Canaries and one in Madeira (Jesus et al., 2013, Pestano et al., 2003). However, no phylogenetic studies have been conducted on the Azorean populations (Rocha, 2020). Some studies conducted in Canary Islands have indicated the possible occurrence of hybridization between *P. maderensis* and *P. kuhli* in some islands (Pestano et al., 2003; Trujillo, 1993).
Pipistrellus maderensis seem to have a similar physiology and life history as pipistrelle populations in Southern Europe (Rocha, 2020), although the species is active throughout the year (Rocha, 2021; Jesus, 2009). In the Canaries, it has been suggested that reproduction may occur during September and October, with females lactating during June and July (Trujillo & Barone, 1993). Data on phenology of the species are not available in Madeira or Azores,

but it is expected that one or two young are born per female in late-May/early June, and that they become independent by the end of summer (Rocha, 2020).

The species can be found in most habitats and is highly influenced by artificial lights, with increased activity around streetlights (Jesus et al., 2009). *Pipistrellus maderensis* roosts are often associated with human-made structures such as roofing tiles and bridges, as well as tree holes (Rocha, 2020). Recent studies indicate that *P. maderensis* is widely distributed in Madeira, with a strong association with shrubland, cropland, and Laurissilva (Ferreira et al., 2022). The species is also more commonly found in lower altitudes, and recent studies suggest that it is sedentary (Barova & Streit, 2018; Rocha, 2020).

As an insectivorous species, *P. maderensis* preys on various agricultural and disease-related insects (Jesus et al., 2009). Although detailed studies on its diet are unavailable, it is suggested that the species forages on moths, small beetles, Diptera, Trichoptera, and Hymenoptera (Rocha, 2021). The species is often found foraging in different types of habitats, with the most common locations being urbanized areas such as streetlights, gardens, and water bodies (Trujillo, 2002; Jesus et al., 2009; Rainho et al. 2002; Rocha, 2020).

The species' echolocation calls vary between approximately 40 and 50 kHz, with durations between 2.1 and 9.5 ms QCF calls in open areas (Rocha, 2020; Jesus et al., 2009). Under cluttered background conditions, the calls tend to be shorter, approximately 2.1-5.8 milliseconds in length, with FM-QCF and peaks ranging from 42.3-51.7 kHz (Teixeira and Jesus, 2009). The frequency values are higher than those of *P. kuhlii* and resemble more closely the calls of its ancestor, *P. pipistrellus* (Teixeira & Jesus, 2009). In contrast, the social calls of this species exhibit the opposite results, as they are more similar to *P. kuhlii* than to *P. pipistrellus*. Lower temperatures and later hours also appear to be associated with a higher occurrence of social calls in the species (Russo, 2009).

There is a significant lack of information regarding diseases and parasites in the species, as well as the population ecology and effects of climate change. In the Madeira and Canary Archipelagos, the species is considered abundant, with an estimated population of fewer than 1,000 individuals in Madeira and no quantification in the Canaries. However, in the Azores, the species is rare, with estimations of less than 300 individuals (Rainho et al., 2002). Due to its limited distribution, *P. maderensis* is considered Vulnerable by the IUCN (Alcade and Juste, 2016). In Portugal, the species is listed as Critically Endangered in the Portuguese Red Book of Vertebrates (Queiroz et al. 2005) and Near Threatened in the Spanish Red Book of Terrestrial Mammals (Trujillo et al., 2008). Also, the species is included in the national and regional protected species lists[2]. The species is protected by the Bern Convention and included in Annex IV of the EU Habitats Directive.

The main threats to the species are associated with the destruction of roosts, such as old buildings and structures, as well as habitat loss by wildfires, the use of pesticides, and introduced predators, such as cats (Trujillo & Barone 1993; Rainho et al. 2002; Jesus et al. 2009; Rocha 2015; Rocha 2020). The species is attracted to streetlights, and while reducing light pollution is important, the use of high-pressure sodium vapor lamps might negatively impact the species' foraging efficiency (Ricardo, 2020).

[2] More data: https://www.biodiversidadcanarias.es/biota/especie/V00007

3.8. Canary long-eared bat (*Plecotus teneriffae* Barret-Hamilton 1904)

Juste et al. (2004) proposed that *Plecotus teneriffae*, an endemic bat species of the Canary Islands, evolved from *Plecotus gaisleri* (North African bat species). Studies indicate that *P. teneriffae* colonized the archipelago more than 2.3 million years ago (Razgour et al., 2020). This medium-sized bat has dark greyish-brown fur that is thicker and darker at the base, and lighter towards the front, with younger individuals having darker colorations. Females are generally larger than males (sexual dimorphism). The ears measure c.a. 40 mm, and the tragus has an outer side that is slightly concave and the bottom convex, measuring over 20 mm (Trujillo, 2012; Razgour et al., 2020).

The reproductive cycle of *P. teneriffae* starts in September. Females give birth in July, and lactation occurs between mid-July and August, with some exceptions (Trujillo, 1991 and 2012). Summer maternity colonies can have between 10 and 30 females, with the largest observed having 61 bats in 1998 (Trujillo, 2012). During winter, the species appears to be solitary or roost in smaller groups of around 10 individuals (Juste & Alcaldé, 2016; Razgour et al., 2020). Hutterer et al. (2015) suggested that the species is mostly sedentary, moving only within close proximity to the roost area.

Plecotus teneriffae can be found in a variety of habitats and altitudes, including coastal areas, woodlands, heathland, and montane scrub. However, it is more frequently observed in Canary Pine forests, as well as transitions from these forests to Laurel forests and Fayal-heather areas (Ibáñez & Fernández, 1985; Trujillo & Barone, 1991; Razgour et al., 2020). The species is often seen foraging in dense forest areas near water sources, and is known to roost primarily in volcanic tubes, caves, water mines, and abandoned buildings, but not in tree holes or bat boxes (Trujillo, 1991; Benzal & Fajardo, 1999; Razgour et al., 2020). It is present only on three islands: Tenerife, La Palma and El Hierro.

Studies on the diet of *P. teneriffae* are limited, but research conducted in 11 caves showed that the species primarily feeds on Lepidoptera, with the main families being Noctuida and Geometridae (Trujillo, 1991). It has also been shown to predate on the pine forest moth pest, *Macaronisia fortunate* (Trujillo & Barone, 1993). Coleoptera remains were found in only a few samples (Razgour et al., 2020). Few studies have been done on the parasites of the species, but Trujillo (1991) identified mites on the species, including *Steatonyssus balcellsi*, *Steatonyssus teidae* and *Spinturnix plecotinus* (Razgour et al., 2020).

P. teneriffae is classified as Vulnerable (VU) by the IUCN due to its restricted distribution and declining population, which has decreased since the 1950s due to aerial fumigation pest control (Juste & Alcaldé, 2016; Benzal & Fajardo, 1999; Razgour et al., 2020). Also, the species is listed as as Vulnerable in the national and regional protected species lists. The species is further threatened by roost disturbances associated with tourism or blocking caves entrances during breeding season, pesticides.

3.9. Analysis of research articles about Macaronesian Bats

Our research found 81 papers from 1966 to 2022 that contained relevant information about bat populations in Macaronesia. As we analysed articles on species present in Macaronesia since 1966, we observed a greater number of papers published during the 2002, 2009, 2011, 2016 – 2017, 2021 – 2022, with a mean increase of six, five, seven, nine and eight papers, respectively (see Fig. 1). On average, 1.5 papers per year related to bat populations in Macaronesia were published over the past years.

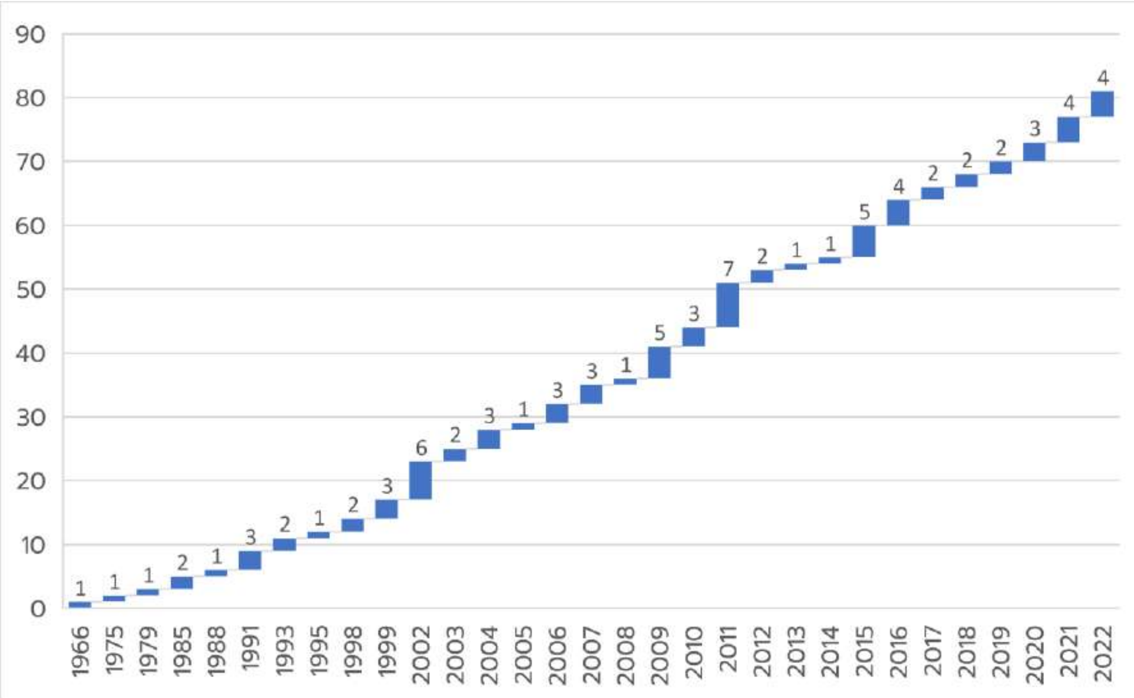

Figure 1. *Cumulative number of papers published found per year written referencing the bat species in Macaronesia.*

Based on our research on the biodiversity of the Macaronesia region, the Azores archipelago has the highest number of articles published on native species of bats (17 research and 7 review articles), followed by Canary Islands (11 research and 7 review articles), Madeira (8 research and 3 review articles) and Cape Verde (7 research and 1 review article). In the Azores, most studies focus on the endemic exclusive species (*N. azoreum*), while Madeira has a higher number of studies associated with the Macaronesia endemic species (*P. maderensis*) (see Fig. 2, Table 2).

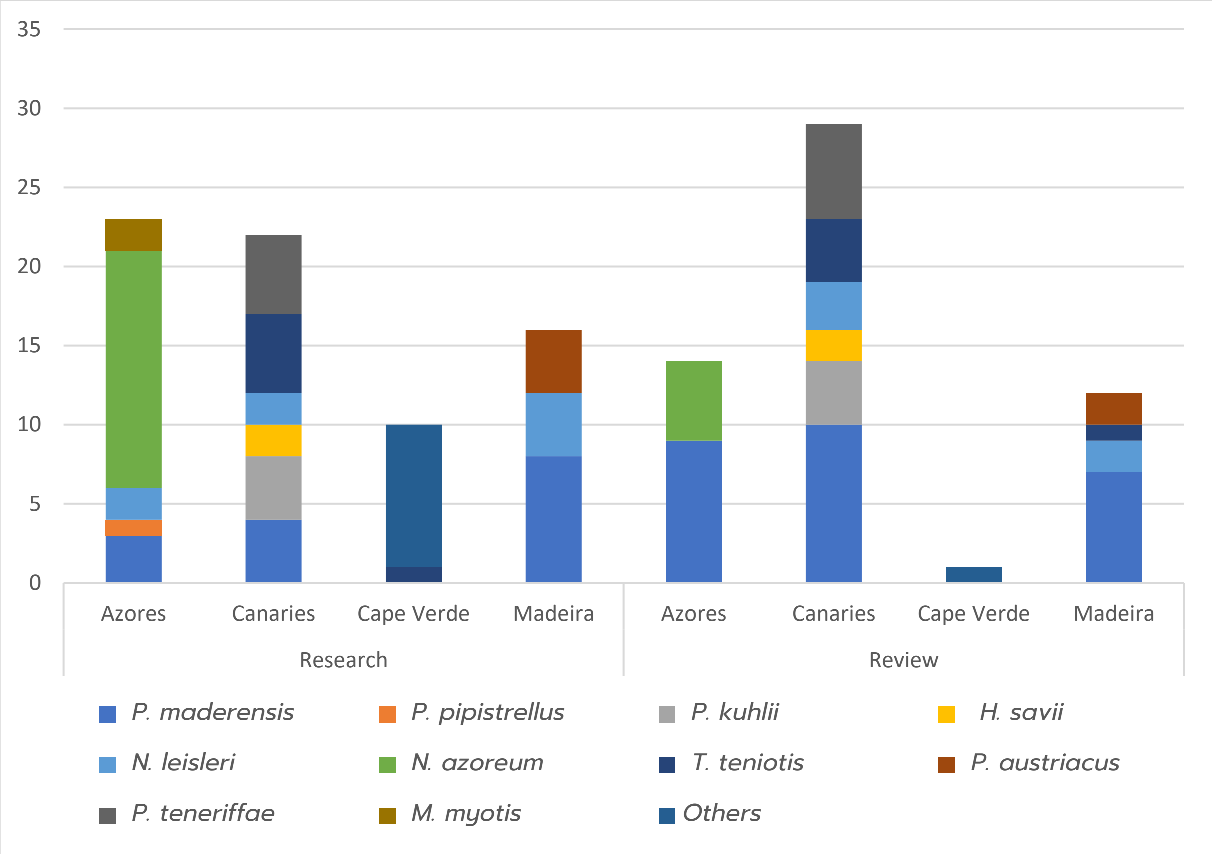

Figure 2. *Geographical distribution of the studies of the different species of bats in Macaronesia*

TABLE 2 Number of papers per archipelago and per species in Macaronesia.

	Research				Review			
	Azores	Canaries	Cape Verde	Madeira	Azores	Canaries	Cape Verde	Madeira
Others	0	0	9	0	0	0	1	0
M. myotis	2	0	0	0	0	0	0	0
P. teneriffae	0	5	0	0	0	6	0	0
P. austriacus	0	0	0	4	0	0	0	2
T. teniotis	0	5	1	0	0	4	0	1
N. azoreum	15	0	0	0	5	0	0	0
N. leisleri	2	2	0	4	0	3	0	2
H. savii	0	2	0	0	0	2	0	0
P. kuhlii	0	4	0	0	0	4	0	0
P. pipistrellus	1	0	0	0	0	0	0	0
P. maderensis	3	4	0	8	9	10	0	7

Based on our research on the biodiversity of bat in Macaronesia, genetics and species review are the most common research topics across all archipelagos (see Fig. 3). However, the Madeiran Archipelago stands out with a greater variety of research topics compared to the Azores and the Canary Islands, which focus more strongly on genetics studies of the species present. Specifically, Cape Verde has the lowest number of publications and a lack of research on topics such as species distribution, ecology, and behaviour, in addition to genetics and species review (see Fig. 3).

Figure 3. *Proportion of the topics in the papers related to the Macaronesian Bat species per archipelago.*

Our researched revealed that several areas of knowledge related to the bat species in Macaronesia is limited. Specifically, we found less research on the anthropological effects (including invasive species), the biology of the island species (Bioacoustics, Land-use, Behaviour, Phylogeny, Reproduction, etc) as well as Species interactions (including inter groups as in predators and diet). Furthermore, we identified some important gaps of knowledge that should be prioritized in Macaronesia such as diet, the roost areas, light pollution effects, parasites and physiology (Dechmann & Ruczynski, 2020; Razgour et al., 2020; Rocha, 2020).

Our research shows that *P. maderensis* is the species in Macaronesia with higher number of papers published, followed by *N. azoreum* (see Fig. 4). However, there is still a lack of research on several aspects of the endemic and native species in Macaronesia. This gap in knowledge highlights the need for further research to increase our understanding of these species and to implement effective conservation measures to protect these endangered species, as recommended by the International Union for Conservation of Nature (IUCN).

As stated before, the studies in Macaronesia seem to focus mainly on the endemic species and most of the papers found are reviews on the studies regarding the species. More studies are needed, particularly in the endemic species, on the different topics such as the impacts of ALAN, land-use, behaviour, roosts, parasites, phylogeny, reproductive cycle and anthropological effects on the Macaronesian bat populations. This knowledge is extremely valuable for the conservation of these vulnerable species and on the construction of an efficient management plan of this insular ecosystems.

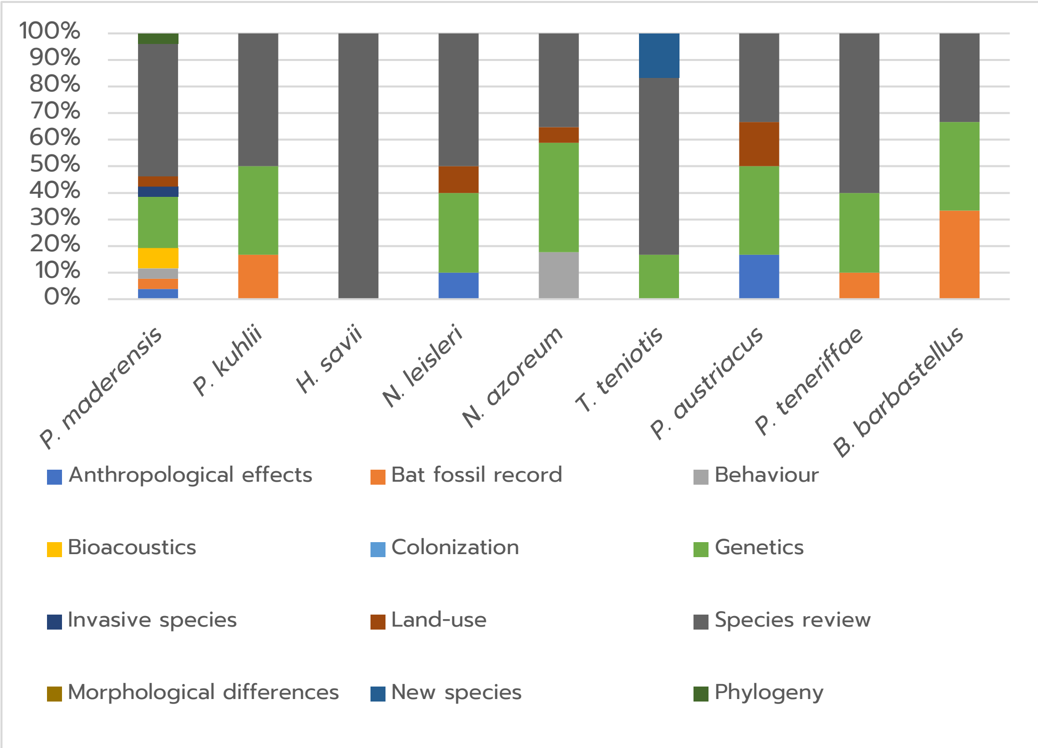

Figure 4. Papers related to each species and the specific information associated on the research or reviews.

4. Chapter II: Effects of ALAN on Bats

Bats, being the second-largest mammal order in terms of species number globally, play an essential role in maintaining global biodiversity. Due to their high diversity and utilization of multiple niches, these mammals serve as important bio-indicators that reveal the impacts of different trophic levels and environmental degradation. Furthermore, bats are susceptible to changes in their ecosystems and are easy to monitor, making them an effective indicator of human impacts on the environment (Fenton et al., 1992; Stone et al., 2015).

Given their critical roles in ecosystems, bats must be included in conservation plans related to ecosystem preservation. Conserving bat populations not only ensures the survival of these species but also maintains the balance of ecosystems (Kalka et al., 2008; Stone et al, 2015). However, human disturbances, especially urbanization, have significant impacts on bat habitats through disturbances such as light and noise pollution. Urbanization contributes to the destruction of roosts and the fragmentation of bat habitats, negatively affecting bat populations (Verboom & Huitema, 1997; Stone et al., 2015).

Bats' foraging activities are also affected by light, such as the natural light-dark cycle (LDC) and moonlight (Aschhoff, 1960, 1965 and 1981; Erkert, 1982; Saldaña-Vásquez & Munguía-Rosas, 2013). The LDC and moonlight influence bats' emergence from roosts, daily patterns, and behaviour, with the time of sunset and sunrise affecting the LDC and moonlight affecting behaviour (Erkert, 1982; Saldaña-Vásquez & Munguía-Rosas, 2013). Artificial lights can negatively affect bat behaviour or indirectly make foraging areas unsuitable for bat populations (Rasey, 2006).

Colonies of different species located in buildings, such as *Plecotus auritus* in Sweden, have decreased in number or disappeared due to the illumination in the area (Rydell et al., 2017). Partial and full illumination of roosts located in buildings has also caused colonies to disappear either immediately or gradually (Rydell et al., 2017). Studies have shown that the illumination of roost entrances affects colonies, with red light having less effect compared to other colours (Downs et al., 2013; Straka et al., 2020; Voigt et al., 2018b; Zagmajster 2014). All foraging guilds appear to be sensitive to artificial light at night close to their roosts (Voigt et al., 2018b, 2021).

ALAN is known to attract nocturnal insects, such as moths, which can in turn attract certain bat species to forage near streetlights (Eisenbeis, 2006; van Langevelde et al., 2011). Observations of foraging bats from genera such as *Myotis*, *Nyctalus, Pipistrellus*, and *Tadarida* near ALAN suggest that these species may be light-tolerant (Stone et al., 2015). However, the activity levels of bats vary depending on the type of light, with higher activity levels observed close to ceramic metal halide (MH) lights compared to low-pressure sodium (LPS) streetlights (Stone et al., 2015b).

Fast-flying bat species from the genera *Eptesicus, Nyctalus* and *Pipistrellus*, which are adapted to forage in open areas, usually benefit from streetlights to forage (Russo et al., 2017; Voigt et al., 2020). Despite their tolerance to ALAN, foraging near streetlights can expose bats to additional risks, such as increased risk of collisions with vehicles and higher predation rates for inexperienced juveniles (Racey & Swift, 1985). ALAN can also cause niche segregation between bat species and alter their predatory behaviour, causing them to forage on larger nocturnal insects close to streetlights (Salinas-Ramos et al., 2021). Meanwhile other species avoid illuminated areas and reduce their foraging activity (Polak et al., 2011; Voigt et al., 2018b). In addition to potential impacts on insect diversity and composition, the presence of streetlights may also lead to the loss of foraging areas for some species (Davies et al., 2012; Lewanzik & Voigt, 2014, 2018b).

It is important to note that while the effects of ALAN on bats can vary depending on the species and foraging guild, the overall negative impacts of artificial lighting on wildlife and ecosystems cannot be ignored and efforts should be made to minimize its effects. The impacts of ALAN on bats can vary depending on the species or foraging guilds and can consequently lead to different impacts on ecosystems (Voigt et al., 2018b, 2021). For instance, foraging guilds associated with open spaces and edge spaces have been observed to actively forage close to streetlights in Scandinavia (Rydell, 1992). Conversely, slow-flying bats such as *Plecotus* and *Myotis* appear to avoid streetlights (Rydell, 1992). However, there are species such as *Nyctalus* noctule and *Barbastella barbastellus*, which are open-space and forest specialists, that have been observed to forage around streetlights, depending on the cost and benefits for the individual (Voigt et al., 2020 and 2021; Russo et al., 2017).

The colour of the lights, as mentioned before, has a significant impact on bat activity around illuminated areas. Studies have shown that white, green, and blue lights increase the activity of *Pipistrellus* bats, but decrease the activity of *Myotis* and *Plecotus* bats (Spoelstra et al., 2015; Zeale et al., 2018). However, red lights do not appear to affect the activity of bat species studied (Spoelstra et al., 2017). Moreover, the decrease in the intensity of streetlights, such as LED lights, has been found to increase the activity of some bat species that usually avoid ALAN (Rowse et al., 2018). Additionally, switching off the illumination during part of the night (Azam et al., 2015) can also have a positive impact on the bat activity. It is important to note that the type of lights used to illuminate the streets can also have a significant effect on the impact of ALAN on bat activity.

4.1 Analysis of research articles about effects of ALAN on bats

Based on our research, we found 46 papers published between 2015 and 2022 that contained relevant information about the effects of Artificial Light at Night (ALAN) on bats, starting from Stone (2015). Upon analysing articles on the impacts of ALAN on bats since 2015, we observed a greater number of papers published during the periods of 2017-2018, 2020 and 2022, with a mean increase of 15, 8 and 7 papers, respectively (see Fig. 5). On average, about 4.6 papers per year related to the impact of ALAN on bat populations were published over the past 8 years.

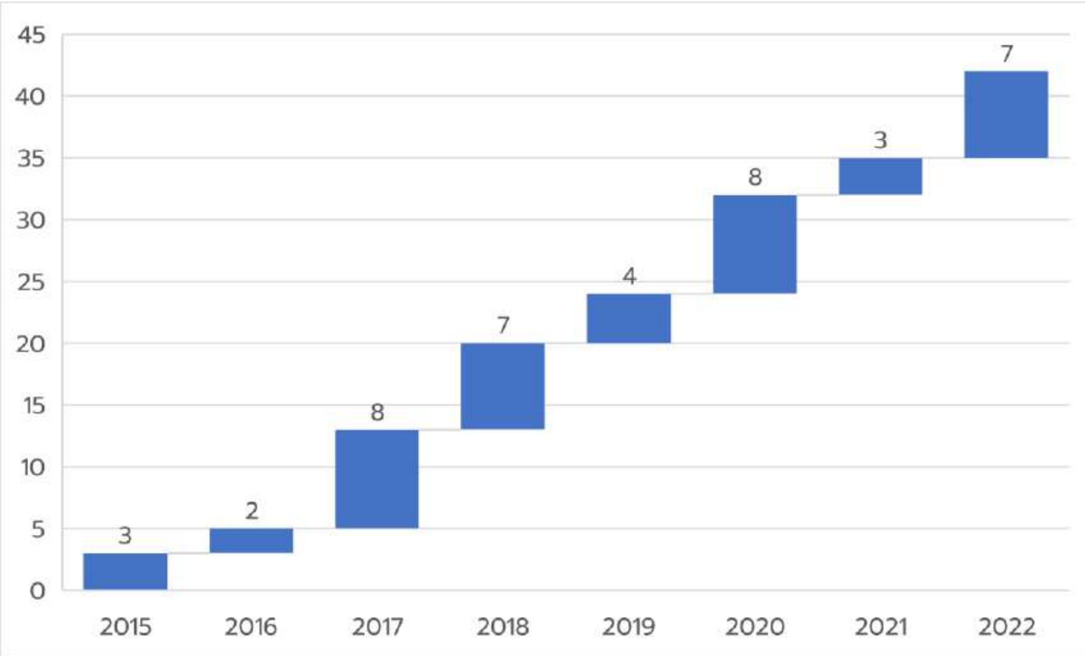

***Figure 5**. Cumulative number of relevant papers published found per year written referencing the effects of ALAN on bats.*

Based on our analysis of studies conducted since 2015, it was found that a significant proportion of research (42%) focused on examining the effects of ALAN on bat activity in general, particularly in relation to streetlights (light effect). These studies described the effects of streetlights on bat activity, showing that fast-flying bats increased or maintained their activity while slow-flying bats decreased or avoided these areas (Azam et al., 2018; Bhardwaj et al., 2020; Haddock, 2018). However, only a smaller percentage of studies (11%) investigated the impact of different types of lamps, such as LPS or LED, used for streetlights. One study found no significant changes in bat behaviour between HPS and LED lamps (Lee et al., 2021). On the other hand, another study reported that the change to LED increased bat activity and diversity, but this was dependent on light intensity (Kerbiriou et al., 2020). Furthermore, only 18% and 5% of studies explored the influence of landscape and urbanization on the effects of ALAN on bat activity, including drinking areas. The most evidence of landscape influence on the impacts of ALAN is related to water areas and tree coverage, which show different results depending on these factors. Drinking areas have been shown to be the most affected by ALAN, with reduced activity of most genera, including *Pipistrellus* spp. (Russo et al., 2017a). However, Voigt et al. (2018a) showed that *Nyctalus noctula* avoided routes with streetlights but was active in well-vegetated water areas. Additionally, non-urban areas appear to have the greatest impact on bat activity, although the effects of ALAN may depend on the landscape (Barré et al., 2022).

Only 5% and 11% of studies were conducted to understand the effect of different colours and intensities of light on bat activity, respectively. Red light and lower-intensity light seem to increase the foraging activity of slow-flying bats while decreasing or not affecting the activity of species such as *P. pipistrellus* (Bolliger et al., 2020; Lacoeuilhe et al., 2014; Spoelstra et al., 2017). Finally, only one paper (2%) reflected on the public opinion on changes in lighting for the conservation of biodiversity (Fig. 6).

In summary, while some studies have examined the general effects of ALAN on bat activity, further research is needed to better understand the impacts of different types, colours, and intensities of light, as well as the influence of landscape and urbanization on bat behaviour. Additionally, public perception of these issues should be taken into account when developing conservation strategies.

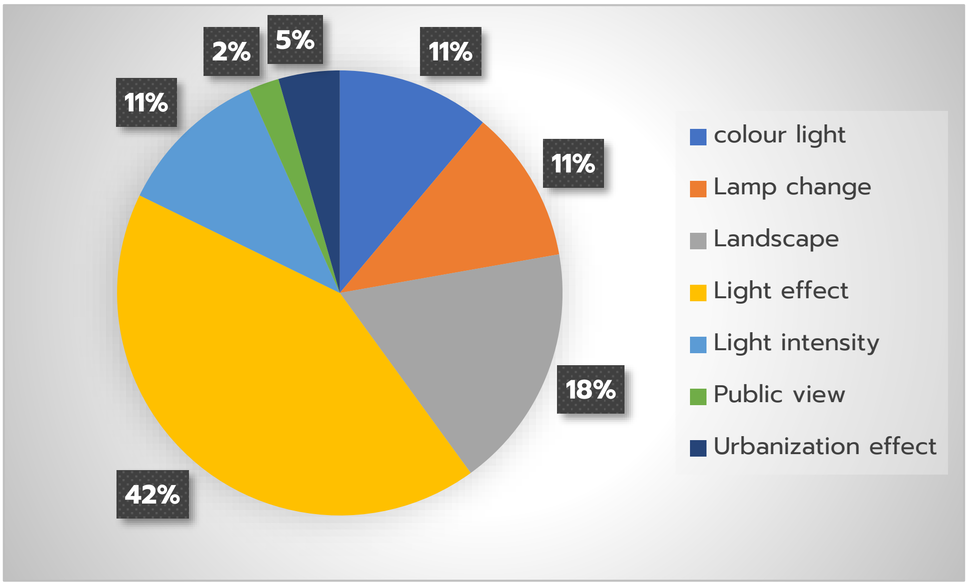

Figure 6. *Proportions of the main study topics in the different selected articles related to the effect of ALAN in bats.*

The majority of studies conducted on the impact of ALAN on bats suggest that it has a negative effect on bat activity (45.2%). The negative effects were observed most commonly in research on the general impact of ALAN (57.8%) and in landscape studies (including water areas, 21.1%). ALAN can significantly decrease the foraging and drinking activity of many species of bats, particularly slow-flying bats, and the impacts may depend on the landscape and water areas (Barré et al., 2022; Hooker et al., 2022; Russo et al., 2017b). Additionally, studies have found that bats may abandon roosts in illuminated buildings (Rydell et al., 2017, 2021).

Interestingly, the percentages of papers reporting neutral, positive, and multifactorial (depending on various variables) results were similar. It is important to note that the results are dependent on various factors such as bat species, tree coverage, colour of the light, or foraging habitat. While most papers did not identify any variables that influenced the results, many studies found that the bat species present played a significant role. For example, fast-flying bats were more attracted to streetlights while forest-associated bats tended to avoid illuminated routes. The colour of the light also significantly affected the activity of bats, although this effect varied depending on the bat species. For instance, *Pipistrellus* spp. were most active in green, blue or white light, while slow-flying bats were most active under red light (Spoelstra et al., 2017).

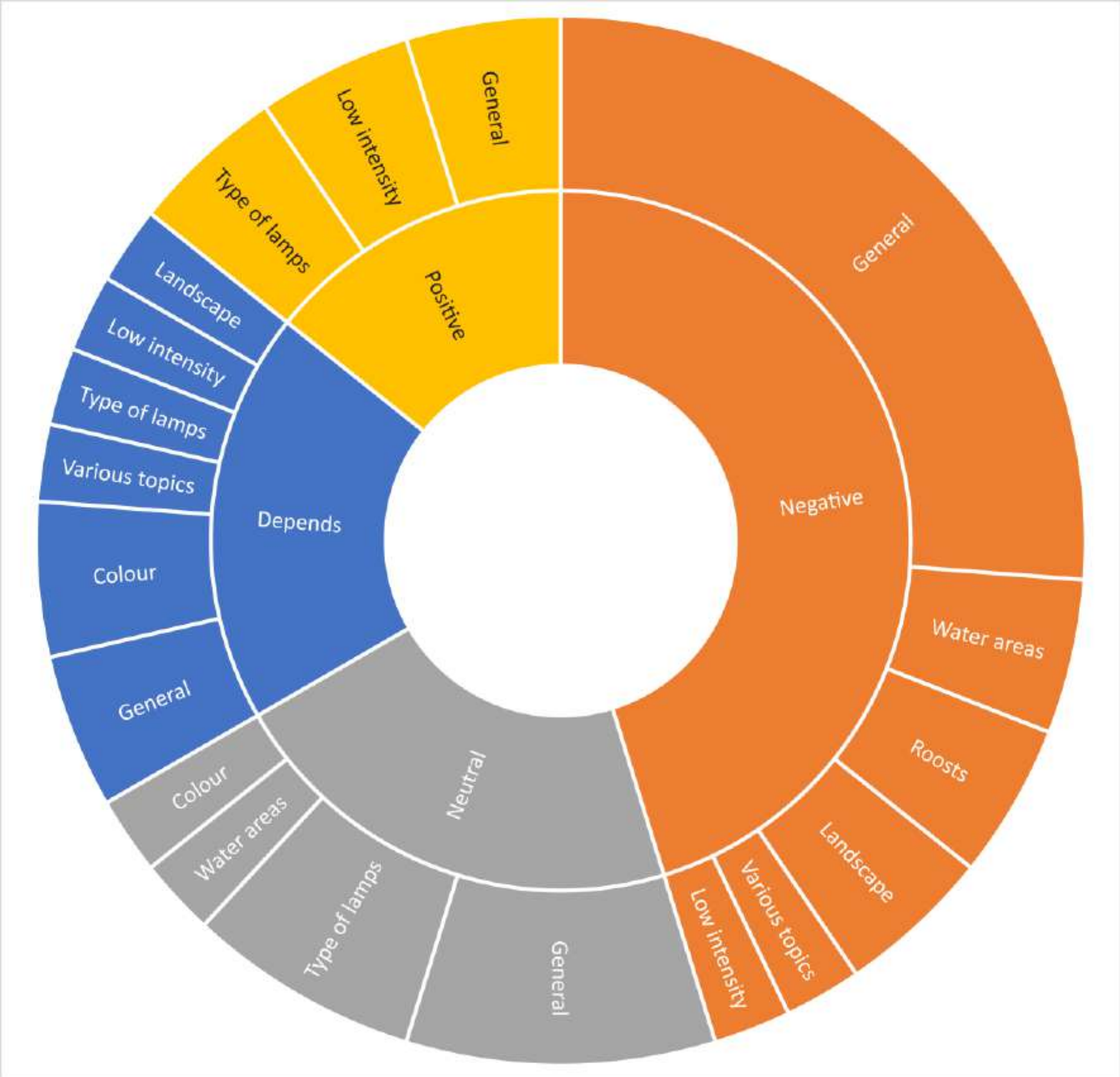

Figure 7. *Proportion of results on the effects of the ALAN (Positive, Negative, Neutral, Depends) on the different types of studies on the relevant papers on the topic.*

Numerous studies have investigated the effects of ALAN on the foraging activity of fast-flying bats, with many showing either positive or neutral effects of light near streetlights

(Salinas-Ramos et al., 2021; Schoeman, 2016; Voigt et al., 2021). However, the intensity of light plays an important role, and some studies have found that reducing light intensity near streetlights can improve the diversity and activity of bats, although there are differences in responses across bat species (Laforge et al., 2019; Rowse et al., 2018; Voigt et al., 2021). As stated before, the colour of light also plays a significant role, with *Pipistrellus* spp. being most active under green, blue, or white light, while slow-flying bats are most active under red light (Spoelstra et al., 2017; Bolliger et al., 2022). However, earlier studies have not found consistent preferences for either warmer or cooler LED lighting on bat activity, and some research suggests that bat activity may be more closely tied to the availability of prey (Bolliger et al., 2020; Haddock et al., 2019; Stone et al., 2012).

5. Chapter III: Mitigation of the effects of light pollution on bats

There are numerous ways to address light pollution through mitigation measures. It is crucial to mitigate light pollution not only to protect bats and associated ecosystems but also to improve energy efficiency and reduce costs. By implementing well-designed lighting plans and utilizing energy-efficient lighting technologies, we can decrease our environmental impact and promote sustainable development. To effectively mitigate light pollution, we can take several steps. For example, we can reduce the intensity of lighting when it is not needed, and switch to energy-efficient bulbs, such as LEDs. Additionally, we can establish lighting ordinances and regulations that limit light pollution. By reducing energy usage, businesses and individuals can save on energy costs and promote sustainable development. Overall, implementing effective mitigation measures for light pollution is a crucial step towards creating a more sustainable planet.

Light pollution caused by illuminated buildings, such as churches, is a significant disturbance to bat colonies. Numerous studies have investigated the impact of light pollution on biodiversity, including bat communities. Research indicates that the illumination of roost entrances in buildings can prevent or reduce the emergence of bats from their roosts. A recent study conducted by Rydell et al. (2017) in Sweden used a before-and-after approach, comparing data from 1980 to 2016, to examine the effects of light pollution on rural churches. Their findings showed that colonies of bats present in partially or fully illuminated churches were abandoned, while the colonies in unlit churches were maintained (Berthinssen, et al., 2021). Overall, this highlights the importance of implementing effective mitigation measures to reduce light pollution in areas where bat colonies are present, such as minimizing or eliminating light around their roosts.

Apart from roost areas, the illumination of foraging, drinking, and swarming areas can also significantly impact the activity of various bat species. In Italy, a study conducted in 2015 aimed to investigate the effects of lighting a drinking area on bat activity. The results of the study revealed that most bat species, including *Barbastella barbastellus*, *Plecotus auritus, Myotis* spp., *P. kuhlii*, and *Hypsugo savii*, were more active in unlit troughs (Russo et al., 2017; Russo et al., 2019; Berthinssen et al., 2021). This finding highlights the importance of minimizing or eliminating lighting in areas where bats are known to forage, drink or swarm. Implementing effective lighting strategies that take into account the behaviour of different bat species can help to mitigate the negative impacts of light pollution and conserve bat populations. Therefore, it is crucial to recognize the significance of these studies in assessing the impact of light pollution on bats and other wildlife.

Streetlights are another significant disturbance to the bat community. However, studies have shown that reducing the light intensity, limiting the number of streets lit, and the duration of illumination can effectively mitigate the negative effects of light pollution. Additionally, changing the type of light can also be an effective solution. A study conducted in southwest England and Wales in 2009 suggested that reducing the light intensity increased the activity of *Rhynolophys hipposideros*.. However, this change did not show any changes in the activity of the *Myotis* genus, even though both species usually avoid illuminated areas (Stone et al., 2012). Further research was conducted in the UK using different intensities of LED lights, which showed that *Myotis* spp. were more active when the LED intensity was dimmed to 25%. However, the activity of *Pipistrellus pipistrellus* decreased, being most active at 50% intensity (Rowse et al., 2018; Berthinssen et al., 2021). These findings highlight the importance of carefully selecting and adjusting the intensity of streetlights to minimize their negative impact on bat populations.

Light pollution can be regulated in several ways to reduce its negative effects on bat communities. One approach is to reduce the number of illuminated areas and the duration of lighting (Voigt et al., 2018b). This can be achieved through the use of motion-activated or time-controlled lighting systems, which ensure that lights are only on when necessary. Many local authorities and councils in the UK have started implementing these measures, switching off or dimming lights during low human activity hours. This resulted in a decrease in carbon and electric consumption by approximately 30%, and a reduction in road accidents after the introduction of variable lighting regimes (Highways Agency, 2011). Reducing the intensity of lights during low human activity hours (e.g., to 30% power) can also help to minimize the negative effects of ALAN on bats (Fure, 2012; Stone et al., 2015). For example, a study conducted in France in 2015 found that turning off streetlights for part of the night increased the activity of two species (*Plecotus* spp. and *Nyctalus noctule*), decreased the activity of one species (*Pipistrellus pipistrellus*), and had no effect on the activity of five other species: P. *kuhlii, P. nathusii, N. leisleri, Eptesicus serotinus* and *Myotis* spp. (Azam et al., 2015; Berthinssen et al., 2021). However, studies have shown that some bat species, such as *Myotis* spp. and *Rhynolophus hipposideros*, prefer unlit areas and decrease their activity in lit areas (Stone et al., 2012; Berthinssen et al., 2021). It should be noted, however, that reducing the intensity of lighting may not be sufficient for all bat species, especially slow-flying bats, as the light levels required for these species may be unsuitable for human requirements (Stone, 2011 and 2015).

As previously mentioned, ALAN can significantly disrupt bat behaviour, affecting their foraging, navigation, and roosting, which in turn threatens the survival of bat populations, a crucial group for many ecosystems. Additionally, the use of ALAN contributes to 19% of global electricity consumption and generates significant CO_2 emissions, estimated to be around 1,900 Mt per year (Hölker et al., 2010). In the European Union, the most common streetlights are sodium vapor lamps, including high-pressure sodium (HPS), low-pressure sodium (LPS), metal halide (MH), and high-pressure mercury vapor lamps (HPM) (Kerbiriou et al., 2020; European Commission, 2011). However, since 2009, most developed countries have been transitioning to light-emitting diodes (LEDs) (Almeida et al., 2014). LED lights are beneficial due to their high luminous efficiency, reduced CO_2 emissions and energy consumption, as well as lower maintenance costs (European Commission, 2011; Almeida et al., 2015; Kyba et al., 2014).

Studies have found that certain bat species, such as *P. pipistrellus*, *P. pygmaeus*, and *Nyctalus/Eptesicus* spp., exhibit higher activity levels around white 2,800 K metal halide lights when compared to orange LPS lights (Stone et al., 2015). However, the switch from LPS to metal halide streetlights may alter the balance of species distribution, and further research is needed to fully understand the effects of this light change on the ecosystem. On the other hand, LED and HPS lights have little to no impact on the same bat species mentioned earlier. In fact, some species, such as *Myotis* spp., even avoid these types of lights (Stone et al., 2012). However, some studies have demonstrated that the transition from LPS to LED lighting can have a significant impact on bat activity, depending on the intensity of the light (Kerbiriou et al., 2020). Furthermore, the effect of the intensity of LED lights might be species dependent and other factors (Stone, 2012; Berthinussen et al., 2021). Kerbiriou et al. (2020) found that the activity of foraging bats can be negatively affected by the intensity of LED lights, with higher light intensities resulting in decreased activity. Although Bolliger et al. (2022) found little effect of different LED types on bat foraging activity, their research did reveal that standard LED lamps (1,750 K, 3,000 K or 4,000 K) resulted in higher foraging activity compared to diffused LED lamps (with an increase of 21.5%). Additionally, fast-flying bat species, such as *P. pipistrellus*, were found to be the most commonly recorded group in the illuminated and dark areas. However, the activity of these bats seemed to be affected by LED colour temperature (activity ratios 1750 K, 3000 K, 4000 K, ~1:0.8:0.9) and the use of diffusers. In some species, such as *Rhinolophus* spp., the use of LED lights at the entrance of roosts can delay or reduce the emergence of bats (Luo et al., 2021).
Furthermore, aside from the type of light used, the tree cover appears to also have strong influence on bat activity. For instance, species associated to forest areas exhibit increased activity near streetlights with enhanced tree cover or with removal of unnecessary streetlights (Straka et al., 2019). Tree covers can create microhabitats that benefits forest bats and other bats by providing prey and protection against predators (Mathews et al., 2015, Pauwels et al, 2019, Barré et al., 2022). Moreover, the tree cover might help reduce sky glow and increase the foraging activity of high-flying bat (Voigt et al., 2018a,b).
When planning changes on streetlights, it is important to be considered the impacts on the prey and the ecosystem. Alan strongly affects insect behaviour and populations. Primarily ALAN attracts moths and diptera therefore creating hotspots for bat foraging (Stone et al., 2017). However, the creation of these foraging hotspots might increase the predation of larger insects while decreasing the predation on smaller insects (Salinas-Ramos et al., 2021). Even though, some species are attracted to the streetlights due to the increased prey abundance, forest bats are affected differently and experience a decrease of the prey availability in the dark areas (Haddock et al., 2018). Therefore, when making changes of streetlights, it is important to consider the ecosystem dynamics for deciding on the changes.
Mitigating the effects of light pollution on bat populations can be achieved through various methods. However, predicting long-term effects of these changes is challenging, making it more expensive and time consuming (Mariton, 2023). Therefore, the use of citizen science for the study of bat populations and the effects of light pollution long term is essential to study long-term effects of light pollution (Borden et al., 2022). Numerous bat-related projects use citizen science for collecting extensive data over the years, enabling of important long-term population trends such as the effects of urbanization or landscape changes (Border et al., 2017).

In conclusion, mitigating the negative effects of ALAN on bat populations is a complex process that requires consideration of various factors such as local conditions and species. One potential solution is to create dark areas to reduce the isolation of slow-flying bat species, but this may not always be feasible due to human needs and perspectives. To address this challenge, studies suggest implementing variable lighting regimes with timed remote switching off or dimming lights during low human activity times and high bat activity periods. Additionally, the use of dim light and LED lighting has also shown promising results in increasing bat activity. Ultimately, a combination of different strategies tailored to local conditions and informed by ongoing research may be necessary to effectively mitigate the negative impacts of light pollution on bat populations.

6. CONCLUSIONS

To improve our understanding of bat populations in Macaronesia, it is essential to conduct further research on the endemic species. Information on their roosts, diet, reproductive cycles, and parasites would help to identify the conservation needs of these vulnerable species. Moreover, studying the impact of ALAN on bat populations in Macaronesia could help to develop effective strategies to mitigate the negative effects of light pollution.

One potential solution to minimize the effects of light pollution on bats in the region is to use low-intensity LED lights. This approach has been shown to increase the activity of light-avoiding species in both urban and non-urban areas. Creating dark areas in protected areas during periods of low human activity could also be effective in promoting connectivity between bat foraging areas. Overall, gathering more information on the biology and ecology of bat species in Macaronesia is crucial for their conservation and management. This could involve conducting more studies on bat populations in the region and developing effective strategies to mitigate the effects of light pollution.

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