

## Introduction

Artificial Light at Night (ALAN) is rapidly increasing worldwide and is now recognised as a major driver of insect decline, with cascading effects on ecosystems. Oceanic islands like the Azores are biodiversity hotspots with many endemic species, yet are particularly vulnerable to multiple threats, including **light pollution**.

Knowledge of nocturnal insects in the Macaronesian Natura 2000 (N2000) network is still limited. **Lepidoptera** (moths specifically) are increasingly valued as bioindicators given their dual ecological role as pollinators and their high sensitivity to artificial light. Also, they are known to be strongly affected by light pollution, which disrupts essential behaviours including navigation, mating and foraging.

In response, the **LIFE Natura@night** project aims to improve understanding of nocturnal biodiversity across the **Azores**, Madeira and Canary Islands, guiding conservation strategies under growing ALAN pressures.

### Project objectives:

- 🦋 **Fill knowledge gaps** and establish a baseline for future conservation on nocturnal insect diversity in Macaronesia.
- 🦋 **Update species inventories** within N2000 areas, with emphasis on threatened/protected species.
- 🦋 **Gather abundance data** to assess ecological roles of nocturnal insects and their seasonal patterns.
- 🦋 **Raise public awareness** of the importance of nocturnal insects and ALAN impacts.

## Material and Methods

Sampling took place in 2022 and 2023 at 26 sites across three islands from the Azores (Graciosa: 14, Corvo: 6 and São Miguel: 6), covering six N2000 areas (Figure 1). Standardised nocturnal insect monitoring used **UV light traps** as the main method, and *winerope* and pitfall traps as complementary techniques (Figure 2).

Each session lasted **four hours** (21:00–01:00) under suitable weather conditions (no rainfall, low wind, favourable moon phase, minimal artificial lighting).

Specimens were identified by **CE3c** experts, who also formed the scientific commission. Only species-level identifications were used in the analysis of biological indices (**Hill Numbers**) and **NMDS** to ensure consistency and data quality to assess species distribution across sampled areas.

## Results

A total of **8,426 insects** were collected, including **4,960 Lepidoptera**, the dominant order across all islands. Graciosa yielded the highest numbers (6,455 insects; 3,542 Lepidoptera; 98.73% identified, 42 species ID), followed by Corvo (1,241; 802; 95.26% ID; 24 species) and São Miguel (730; 616; 98% ID; 26 species).

Among Lepidoptera, **Microlepidoptera** represented a **79.4%**. In total, **15 families** were identified. The most abundant being Crambidae (2,047), Noctuidae (1,016), Argresthiidae (604). Graciosa recorded all families; Corvo 8; and São Miguel 7. Overall, Lepidoptera composition (98% ID) comprised **61.2%** native (NAT), **21.2%** endemic (END), and **11.6%** introduced (INT) species. Patterns varied among sampled N2000 areas and islands (Figura 3). **Graciosa**: 55.3% NAT, 13.8% END, 21.1% INT. **São Miguel**: 47.4% END, 52.5% NAT, 10.2% INT. **Corvo**: 39% END, 32.2% NAT, 13% INT, highest unclassified (15.8%).

**Most sites were dominated by native taxa**, followed by END AZO, while INT species were generally scarce. Graciosa showed the highest overall abundance and a comparatively higher proportion of introduced species whereas Corvo and São Miguel had higher percentages of END AZO & NAT species.

A total of **15** endemic species were found. Eleven endemic Lepidoptera under legal protection were recorded (Figure 4).

## Discussion

This study presents the first systematic inventory of nocturnal insects in the Azores, focusing on nocturnal Lepidoptera and light pollution. Results reveal marked N2000 area and island-level differences in abundance and composition, underlining the need for targeted conservation.

- 🦋 **Lepidoptera dominated across all islands**, confirming their vulnerability to ALAN. **Light traps** proved **highly effective** for capturing Lepidoptera, while complementary methods improved taxonomic resolution.
- 🦋 **Insect abundance was higher under low moonlight levels**, highlighting ALAN effects on nocturnal insect behaviour.
- 🦋 **Higher species richness was recorded in well-preserved habitats**, highlighting the importance of native habitats for sustaining nocturnal insect diversity
- 🦋 Introduced species, though fewer, represent additional pressures alongside habitat loss and light pollution.

Across the Azores, native species were most abundant, followed by endemic species, while introduced species remained a small but consistent fraction. **Graciosa** showed the **highest insect abundance** (reflecting the greater sampling effort) and more introduced taxa, reflecting degraded habitats, although, still harbouring rare species. **Corvo** had notable endemic richness despite fewer samples, suggesting that the island hosts a significant biodiversity while **São Miguel** held the **highest proportion of endemic species**, linked to better-preserved habitats.

Several endemic species collected are legally protected (Figure 4), with São Miguel and Corvo holding the highest proportions. For example, among these endemic species, *Argyresthia atlanticella* was abundant across all islands. As a light-sensitive indicator species (Santa Rita et al., 2020), its presence highlights the ecological risks posed by increasing light pollution.

This study demonstrates the urgency of integrating nocturnal insect monitoring into conservation strategies, as baseline data are essential to protect island biodiversity against ALAN, habitat degradation, and invasive species.

## Acknowledgements

This study was conducted as part of the LIFE Natura@night project (LIFE20 NAT/PT/001098), with financial support from the LIFE Programme. The project addresses light pollution threats to biodiversity in Macaronesia, including nocturnal insects, bats and seabirds, aiming to reduce its social, economic and environmental impacts in N2000 areas, while raising public awareness and fostering community engagement. We gratefully acknowledge all volunteers and interns who contributed to this study. For more information, visit <https://naturaatnight.spea.pt/>.

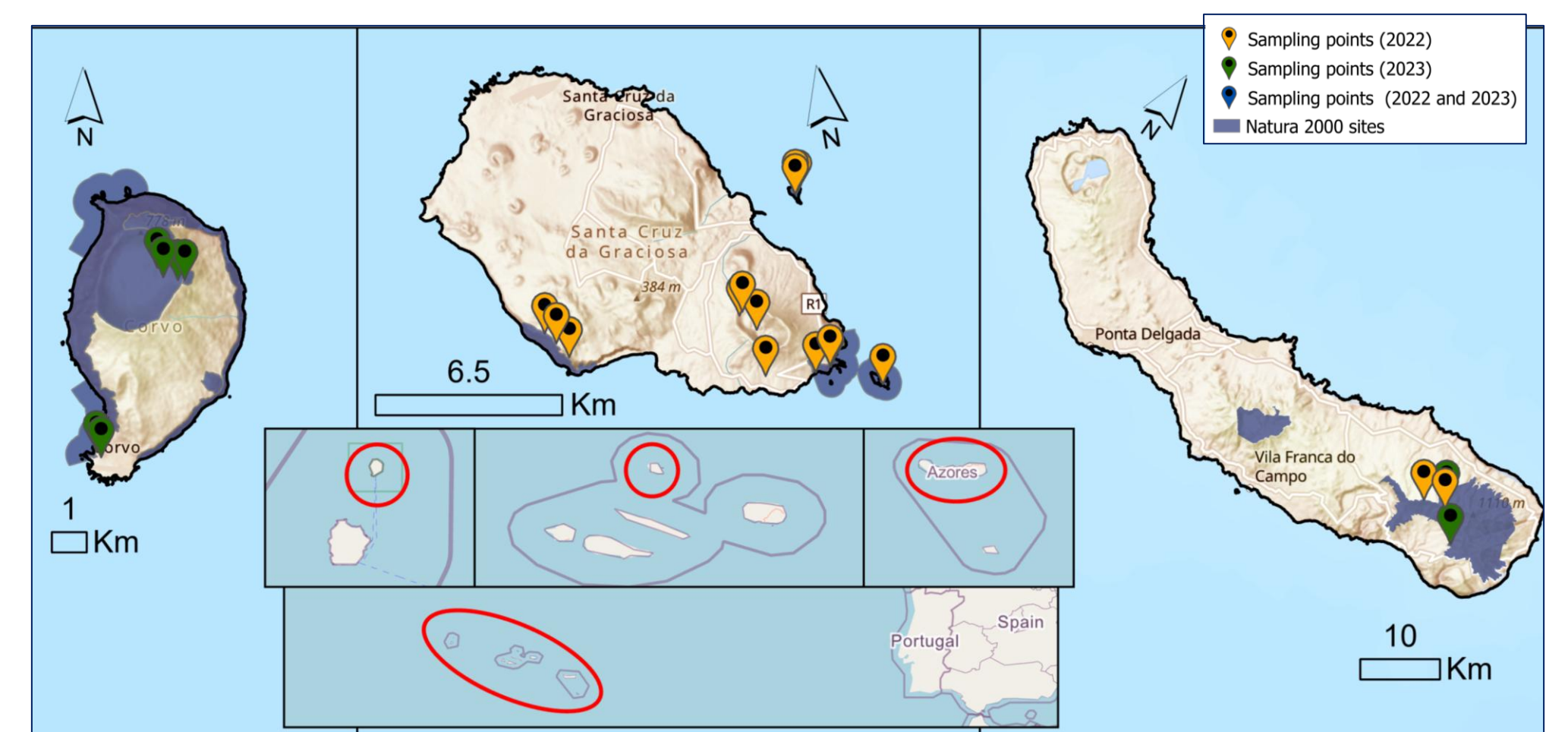
## References

Borges, P., Lamelas-Lopez, L., Andrade, R., Lhoumeau, S., Vieira, V., Soares, A., ... & Assing, V. (2022). An updated checklist of Azorean arthropods (Arthropoda). *Biodiversity Data Journal*, 10, e97682.

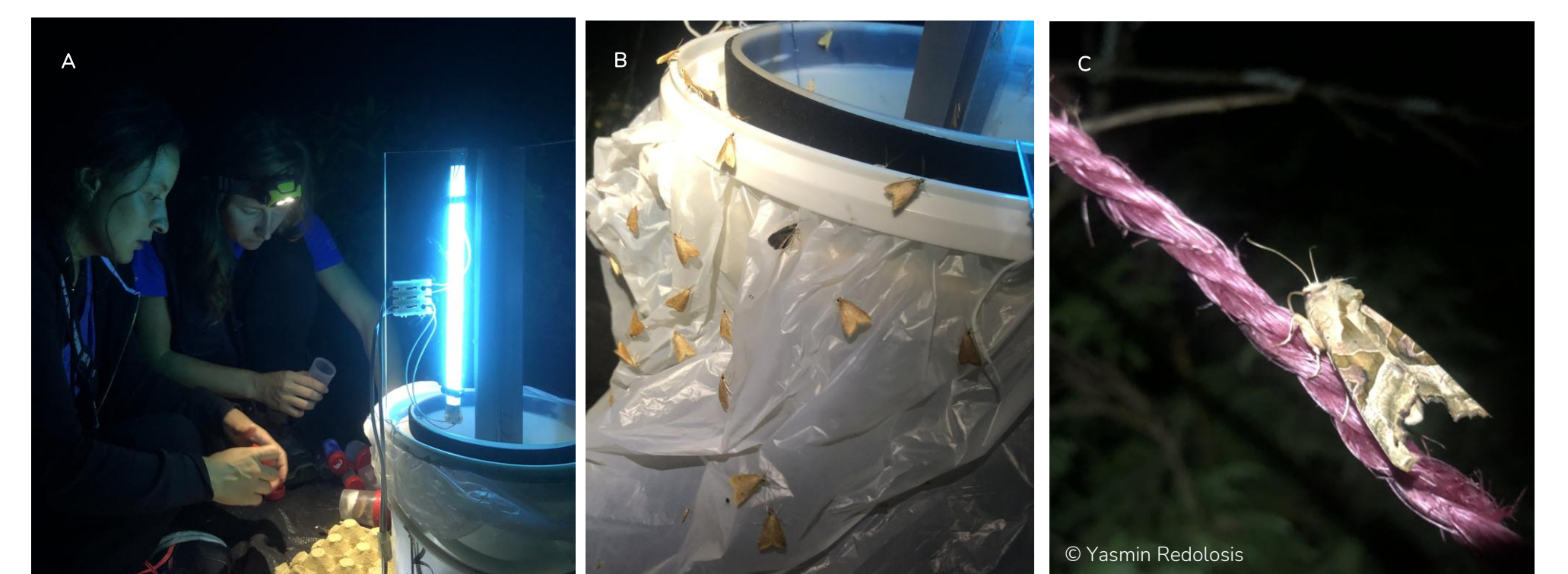
Borges, P., Santa-Rita, J. P., Nunes, R., Danielczak, A., Hochkirch, A., Amorim, I., ... & Vieira, V. (2018). Species conservation profile of moths (Insecta, Lepidoptera) from Azores, Portugal. *Biodiversity Data Journal*, 6, e23311.

Santa-Rita, J. V. P., Baixeras, J., & Karsholt, O. (2020). The enigmatic case of the genus *Argyresthia* in the Azores Islands (Lepidoptera: Argresthiidae). *Zootaxa*, 4789(1), zootaxa-4789.

van Koppenhagen, N., Gossner, M. M., Haller, J., & Bolliger, J. (2025). Mitigating light pollution impacts on arthropods based on light-emitting diode properties. *Conservation Biology*, e70137.

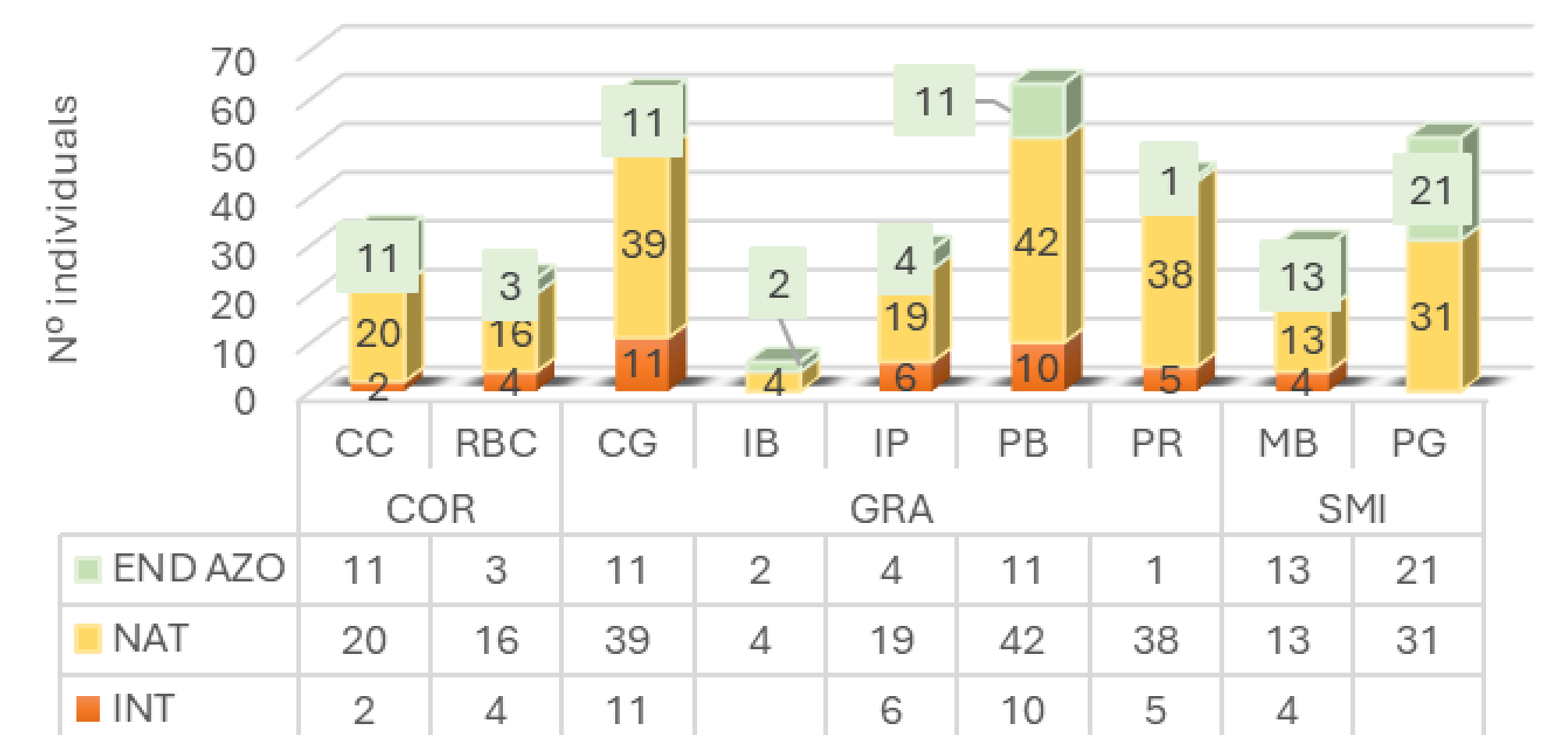


**Figure 1 |** Sampled areas in the Azores. Sampled N2000 sites are shown in blue. Sampling effort included 6 points on Corvo Island, 14 on Graciosa Island, and 6 on São Miguel Island.



**Figure 2 |** A: Collecting insects attracted to a light trap. B: *Udea ferrugalis* attracted to light trap. C: *Phlogophora meticulosa* recorded using the winerope method.

## Biogeographical Status of Identified Lepidoptera Species in the Azores



**Figure 3 |** Biogeographical composition of identified Lepidoptera across the sampled Azores islands (COR, GRA, SMI). Categories include Azorean endemic (END AZO), native (NAT), and introduced species (INT).

Family	Genera	Species	Category	Conservation Status	Sampling Presence
Argyresthiidae	Argyresthia	Argyresthia atlanticella	END AZO	Near Threatened	Graciosa (IB01, IP01, CG01, CG02, CG03, CG04, PB02, PB03), São Miguel (PG01, PG03, PG04, MB01, MB02), Corvo (CC01, CC02, CC03)
Crambidae	Scoparia	Scoparia aequipennis	END AZO	Least Concern	Graciosa (PB02)
Geometridae	Cyclophora	Cyclophora azorensis	END AZO	Least Concern	Graciosa (PR02, IP01, IP02, IP03, CG01, CG04, PB02, PB03), São Miguel (PG01, MB01, MB02), Corvo (CC01, RBC01)
Noctuidae	Hadena	Hadena azorica	END AZO	Critically Endangered	Graciosa (PR01, PR03, IB01), São Miguel (PG02)
Noctuidae	Mesapamea	Mesapamea storai	END AZO	Least Concern	Graciosa (CG01, CG02, PB01, PB03), São Miguel (PG01, PG02, PG03, PG04), Corvo (CC01, CC02, CC03, CC04)
Crambidae	Eudonia	Eudonia lutealis	END AZO	Least Concern	São Miguel (PG04), Corvo (CC01)
Noctuidae	Phlogophora	Phlogophora fumasi	END AZO	Vulnerable	São Miguel (PG01, PG02, PG04)
Noctuidae	Phlogophora	Phlogophora interrupta	END AZO	Least Concern	São Miguel (PG02, PG04)
Noctuidae	Phlogophora	Phlogophora cabrali	END AZO	Near Threatened	São Miguel (PG04, MB01, MB02)
Noctuidae	Apamea	Apamea sphagnicola sphagnicola	END AZO	Endangered	São Miguel (PG03, PG04, MB02)
Noctuidae	Noctua	Noctua atlantica	END AZO	Least Concern	São Miguel (PG01)

**Figure 4 |** List of Lepidoptera species with a compromised conservation status and their occurrence across the sampled sites in the Azores. Data extracted from the identified species list.