A national checklist for monitoring Portugal's pollinators (Anthophila, Syrphidae and Papilionoidea) under the EU Nature Restoration Regulation

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Abstract

1. Wild pollinators are declining across Europe, prompting new policy commitments. The EU Nature Restoration Regulation requires Member States to reverse pollinator decline and to monitor pollinator abundance and species richness. Effective implementation depends on robust national taxonomic baselines that define which species are present, where they occur and how they can be monitored consistently.

2. We present a policy-oriented national checklist for insect pollinators in the Portuguese territory, covering the three focal groups of the European Pollinator Monitoring Scheme: bees (Hymenoptera: Anthophila), hoverflies (Diptera: Syrphidae) and butterflies (Lepidoptera: Papilionoidea). The checklist covers mainland Portugal and the Azores and Madeira archipelagos, combining published faunistic sources, updated nomenclature, distributional information and monitoring-relevant status fields in a FAIR, Darwin Core-compatible framework, all subjected to expert revision.

3. The checklist highlights the exceptional richness and conservation relevance of the main Portuguese pollinator groups, with 1135 species recorded. Bees are the richest group, with 746 Anthophila taxa, including 736 from mainland Portugal, 24 from Madeira and 19 from the Azores. Hoverflies are represented by 232 Syrphidae species, including 223 from mainland Portugal, 26 from Madeira and 24 from the Azores. Butterflies comprise 151 accepted Papilionoidea taxa, including 140 from mainland Portugal, 18 from Madeira and 12 from the Azores. Island faunas include distinctive endemic and conservation-priority taxa, highlighting the importance of the archipelagos for pollinator conservation.

4. We propose a monitoring-ready framework that distinguishes core monitoring species, extended monitoring species and priority conservation taxa. This framework recognises differences in detectability, taxonomic difficulty, habitat specialisation, restoration sensitivity and conservation relevance.

5. By integrating taxonomic curation, territorial distribution, monitoring tiers and FAIR data principles, this checklist provides an operational reference layer for the Portuguese Pollinator Monitoring Scheme. It supports national implementation of EU restoration targets and creates a traceable baseline for future updates, long-term trend assessment and adaptive conservation planning.

Keywords (6–8): Darwin Core; FAIR data; pollinator checklist; Portuguese Pollinator Monitoring Scheme (PT-PoMS); restoration ecology; species inventory; taxonomic backbone; biodiversity monitoring.

1. Introduction

Long-term, standardised monitoring is essential for distinguishing sustained ecological change from short-term variability and for evaluating restoration outcomes rather than effort alone (Borges et al., 2018; Stephenson et al., 2022). This is particularly important for pollinators, whose trajectories are shaped by multiple interacting pressures, including land-use change, pesticide exposure, invasive species, disease and climate, and may fluctuate strongly among years (Potts et al., 2010). European evidence that pollinating insects and insect-pollinated plants can decline in parallel further underlines the need to monitor pollinators as components of wider ecological networks, rather than as isolated taxa (Biesmeijer et al., 2006). Without standardised, repeatable datasets, it becomes difficult to separate restoration signals from background variability, to detect early warnings of network-level change, compare interventions across landscapes, or assess whether policy targets are being met. Monitoring networks should therefore be built around stable sampling units, documented effort, consistent protocols and interoperable data systems capable of supporting robust trend estimates through time.

Insect pollinators are key elements in our ecosystems, supporting the reproduction of most flowering plants and sustaining both terrestrial biodiversity and agricultural production, yet multiple lines of evidence indicate widespread and concerning declines (IPBES, 2016; IPBES, 2019; Potts et al., 2010; Ollerton et al., 2011; Powney et al., 2019; Warren et al., 2021). In response, European policy has moved toward legally anchored targets and harmonised indicators that require standardised species-informed monitoring of key pollinator groups (Potts et al., 2024). This monitoring approach has now been incorporated into the EU Nature Restoration Regulation, which requires Member States to collect data on pollinator abundance and species richness and to implement measures to reverse pollinator decline by 2030 (European Commission, 2025). Recent horizon scanning for European wild pollinators further identified the Regulation as a world-leading and once-in-a-generation opportunity, because Article 10 establishes legally binding obligations for both pollinator restoration and monitoring across the EU (Morrison et al., 2026)

Portugal is a biologically diverse country. It lies on the western edge of the Mediterranean Basin biodiversity hotspot, a globally important centre of plant and animal diversity that explicitly includes the Iberian Peninsula and Macaronesian archipelagos (Myers et al., 2000; Kass et al., 2022). Despite its relatively small area, Portugal encompasses a remarkable diversity of biogeographical settings. On the mainland, it lies at the interface between Atlantic and Mediterranean climatic influences and between Europe and Africa, and shows marked latitudinal, altitudinal and coastal-interior gradients, which generate a fine-grained mosaic of habitats and land-use systems (Mora & Vieira, 2020). This richness can be further explained by a relative climatic stability and heterogeneity of the Iberian Peninsula through Pleistocene glacial cycles as one of the main southern European refugia, favouring not only the long-term persistence of lineages during climatic oscillations, but also periods of geographical isolation that promoted local diversification and the evolution of local adaptations and the emergence of endemic taxa (Hewitt, 2004). Recent Iberian-scale arthropod prioritisation also shows that conservation-relevant richness patterns differ markedly among taxa, reinforcing the need for broad, spatially explicit biodiversity baselines (Sánchez-Fernández et al., 2026). In parallel, the Macaronesian archipelagoes contribute with a distinct and equally significant evolutionary legacy. Their oceanic isolation, volcanic origin, wide range of geological ages (e.g., ~0.3 Ma for Pico island to ~27 Ma for Selvagens islands), and climatic buffering have allowed the persistence of ancient Tertiary

lineages alongside extensive *in situ* diversification, resulting in relative exceptional levels of endemism across multiple taxonomic groups. For many of these lineages, Portugal is the sole political entity responsible for their conservation (Borges et al., 2008, 2022; Fernández-Palacios et al., 2011).

In recent years, Portugal has advanced pollinator conservation, driven by the EU Pollinators Initiative and the country's Theory of Change process for a national pollinator action plan (Castro & Loureiro, 2025). This process culminated in the development and governmental adoption of the National Action Plan for Pollinator Conservation and Sustainability (Ministry of Environment and Energy, 2026). In line with the commitments assumed by EU Member States, the Portuguese pollinator action plan includes ecosystem restoration measures and proposes a national pollinator monitoring scheme (PT-PoMS) to be implemented by conservation authorities. In parallel, Portugal has developed its National Nature Restoration Plan under Regulation (EU) 2024/1991, building on and incorporating relevant measures proposed under the national pollinator action-plan. Together, these policy developments strengthen the need for restoration actions to be supported by robust evidence base and operational, standardised monitoring tools, including taxonomically curated checklists and baseline data, that can be applied consistently across landscapes and reported transparently to enable adaptive management.

A master checklist of pollinators with conservation, taxonomic and monitoring relevance should, therefore, be grounded in the most up-to-date evidence available, ranging from museum-curated collections to biodiversity inventory platforms, provided that records are subject to expert review. In line with these requirements, the EU Commission has funded multiple projects to overcome current gaps in taxonomic knowledge, namely the Horizon Europe project TETTRIs, which has, for the first time, financed satellite projects specifically devoted to pollinator biological collections. In Portugal, this generated the ARCADE project (Aligning Reference Collections with Taxonomic Development Efforts for pollinator conservation in Portugal; https://tettris.eu/3rd-party-projects/arcade/), whose baseline task involved the production of an updated list of pollinator species.

Here, we provide a policy-oriented and taxonomically curated checklist of Portuguese main wild pollinators, covering bees, hoverflies and butterflies, the three focal groups of the European Pollinator Monitoring Scheme. By integrating updated nomenclature, occurrence-status information, monitoring-relevant descriptors and distributional data for mainland Portugal, the Azores and Madeira, the checklist is designed to serve as the taxonomic backbone of the Portuguese Pollinator Monitoring Scheme (PT-PoMS). It establishes the taxonomic and biogeographic baseline required for standardised long-term monitoring, transparent national reporting and robust evaluation of pollinator responses to restoration measures under the EU Nature Restoration Regulation and related national biodiversity policies (Potts et al., 2024).

Materials and Methods

Geographic scope

The geographical scope of this study covers the entire Portuguese political territory, encompassing mainland Portugal on the Iberian Peninsula and the two autonomous Atlantic archipelagos of the Azores and Madeira (Fig. 1). This delimitation is essential for assembling a monitoring-ready national baseline that reflects both continental and oceanic-island biodiversity contexts (Castro & Loureiro, 2025). Biogeographically, the scope of this work includes three main biogeographical regions: Atlantic (NW continental Portugal), Mediterranean (most of continental Portugal) and the Macaronesian region (Azores and Madeira).

Portugal mainland occupies the western margin of the Iberian Peninsula, with an extensive Atlantic coastline and strong north–south and coast–interior contrasts shaped by major river basins (e.g., Douro and Tagus) and uplands culminating in Serra da Estrela, the highest massif in continental Portugal (1993 m a.s.l.) (Fig. 1a). The Azores form a remote North Atlantic archipelago of nine volcanic islands aligned with the Mid-Atlantic Ridge, where tectonic setting and rugged relief generate steep environmental gradients over short distances; geographically, the archipelago spans approximately 36°–41° N latitude and 24°–33° W longitude (Fig. 1b). The Madeira archipelago lies in the North Atlantic 600 km away from North Africa at approximately 32.7° N, 17.0° W. It comprises two main islands (Madeira, Porto Santo) and several smaller islands. Madeira's central highlands, reaching 1852 m a.s.l., and deeply incised valleys generate strong elevational and aspect-driven microclimates across a small area and a plethora of habitats under different influences (Fig. 1c).

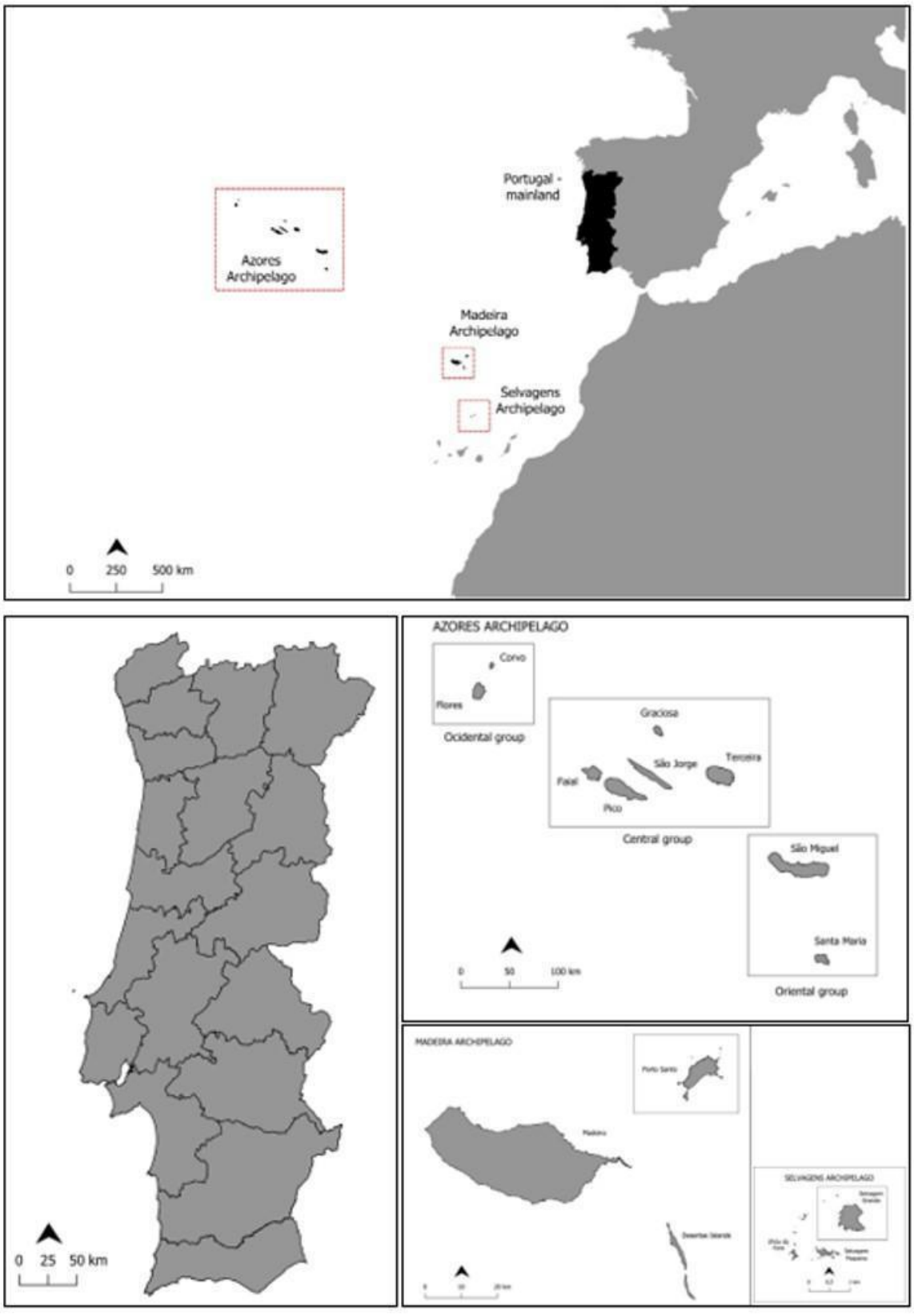

Figure 1. Study area. Mainland Portugal, the Azores and Madeira archipelago (including

Selvagens archipelago) are shown as the three territorial units.

Taxonomic scope and main data sources

This study includes a major subset of Portuguese wild pollinators, namely bees (Hymenoptera: Anthophila), hoverflies (Diptera: Syrphidae) and butterflies (Lepidoptera: Papilionoidea) (see Appendix 1). These correspond to the focal pollinator groups of the European Pollinator Monitoring Scheme and the taxa targeted for harmonised monitoring under the EU Nature Restoration Regulation (European Commission, 2025). Additionally, the European Pollinator Monitoring Scheme also includes moths because of their increasingly recognised value as important nocturnal pollinators (Macgregor & Scott-Brown, 2020), although they are still comparatively understudied and poorly integrated into standard pollinator monitoring frameworks. Given the still-limited species-level data on moth distribution, flower visitation and pollen transport for Portugal, we do not include moths in the present checklist-based monitoring framework; their future incorporation is under development, requiring a dedicated design and approach.

The checklist occurrence-status categories follow established European country checklists and biodiversity data standards (e.g., national faunistic catalogues and GBIF/Darwin Core “occurrence status” and “establishmentMeans” conventions), and include present records, native and non-native (introduced) taxa, endemic species where applicable, regionally extinct taxa, as well as doubtful records, thereby ensuring consistency with prevailing country-record approaches used in European biodiversity synthesis and monitoring frameworks.

The checklist of bees, hoverflies and butterflies (Appendix 1) follows the most recent published taxonomic assessments, online biodiversity datasets, and revisions of museum collections conducted within the ARCADE project.. It will be governed as a versioned Darwin Core-compatible resource, with periodic expert-panel review and a changelog documenting all additions, exclusions, nomenclatural changes, distributional revision and status updates. As taxonomic and phylogenetic research progresses and species distributions continue to change, future updates to the checklist are expected. Names and identifiers will be periodically checked against relevant European taxonomic backbones to preserve comparability across national releases and EU-level assessments.

BEES

The Anthophila fauna has received a substantial boost in taxonomic knowledge at the European level over the past five years, in order to resolve standing taxonomic problems in several genera, update existing checklists, describe previously undescribed species, and produce identification tools and training resources through multiple EU-funded projects. At the national level, the largest existing collections are being revised (Baptista et al., 2026; Gaspar et al., 2025), and extensive exploratory sampling is being conducted. In mainland Portugal, the first comprehensive checklist was published in 2018 (Baldock et al., 2018), compiling many internationally held records and all previously published works (mostly locally and/or taxonomically limited). Since then, 80 species have been added and 24 species removed, raising the mainland checklist to 736 species, following the revision of the large historical collection at the Science Museum of the University of Coimbra in 2025 (Gaspar et al., 2025), and a further update based on the collection of the National Museum of Natural History and Science of the

University of Lisbon in 2026 (Baptista et al., 2026), while also incorporating recent nomenclatural changes (Ghisbain et al., 2025).

The most consolidated taxonomic baseline for Azorean bees was provided by the archipelago-wide annotated checklist of wild bees (Weissmann et al., 2017), which remains the primary reference for confirmed occurrences and colonisation status assessments. This is complemented by subsequent synthesis and updates within the broader updated checklist of Azorean arthropods (Borges et al., 2022) – fixing the number of species at 19.

For the Madeira archipelago, a checklist of bee species is available in Borges et al. (2008). New species have since been described (e.g., Kratochwil & Scheuchl, 2013) and subsequent studies have updated this species list, particularly for Madeira Island (Kratochwil et al., 2018; Kratochwil & Schwabe, 2018; Kratochwil et al., 2022, 2025). Currently, there is no single up-to-date reference work that consistently confirms the occurrence and distribution of bee species within the archipelago.

The mainland fauna comprises around 75 species endemic to the Iberian Peninsula, as well as around 15 North African species whose European distribution is restricted to Portugal. Only one species is considered endemic to mainland Portugal: *Colletes dinizi* Kuhlmann, Ortiz & Ornosa, 2001. Additionally, Portugal hosts two bee genera endemic to Europe, *Flavipanurgus* and *Halopanurgus*, representing two of the three European endemic bee genera, all of which are restricted to the Iberian Peninsula. The Azores archipelago harbours a single endemic species, *Hylaeus azorae* (Warncke, 1992), whereas Madeira supports eight endemic species, representing approximately one third of its known bee fauna.

HOVERFLIES

Hoverflies remain comparatively understudied in Portugal. Despite recent advances in identification resources and regional surveys, substantial taxonomic and faunistic gaps persist, with many records scattered across different publications and several groups still requiring revision.

The most recent dedicated catalogue of the hoverflies of continental Portugal was published by van Eck (2016), who added 28 species to his previous catalogue (van Eck, 2011), bringing the total number of species at that time to 195. Subsequent additions gradually increased this number to 206 species by 2020 (van Eck et al., 2020). More recently, an updated, comprehensive national species list was provided in the supplementary material of Reverté et al. (2023), incorporating some later records and nomenclatural updates, bringing the list to 221 species. Additional contributions expanding the known Portuguese syrphid fauna have also been published in recent years, including works by Almeida (2024) and Gil & Grosso-Silva (2025), among others.

The most recent assessment in the Azores, combining targeted field sampling with expert validation of ‘citizen-science’ records (e.g., iNaturalist and Observation.org), updates the known hoverfly fauna to 24 species (Bot et al., 2025), increasing the previous total of 23 species (Borges et al., 2022). Three endemic species are known from this archipelago: *Eristalis azorensis* Bot, Hofstee & Mengual, 2025, *Shaerophoria nigra* Frey, 1945 and *Xanthandrus azorensis* Frey, 1945. However, there is still a considerable knowledge gap on the syrphid fauna between Azorean islands, and reports of several species to the Azores need confirmation.

The Syrphidae of the Madeira archipelago were most recently reviewed by Smit (2008), who updated the number of species to a total of 26, including four endemic species: *Eumerus hispidus* Smit et al. 2004, *Melanostoma wollastoni* Wakeham-Dawson et al., 2004, *Myathropa usta* (Wollaston, 1858), and *Xanthandrus babyssa* (Walker, 1849). Rego et al. (2022) developed a pictorial key for the known species, this representing the most recent local assessment of the family Syrphidae.

BUTTERFLIES

Portugal features a moderately rich butterfly fauna (Papilionoidea). Across the mainland and the Atlantic archipelagos, the country records more than 150 different Papilionoidea taxa, of which around 147 are species-level, distributed across five main families: Papilionidae (swallowtails), Pieridae (whites and yellows), Lycaenidae (blues and hairstreaks), Nymphalidae (brush-footed butterflies), and Hesperiidae (skippers). Whilst the Portuguese mainland harbours circa 139 butterfly species (Corley, 2015; Maravalhas, 2003; this work), the archipelagos are impoverished, albeit including a unique assemblage of palaeotropical elements, temperate dispersalists and narrow or Macaronesian endemics: 18 taxa in the Madeira archipelago (Borges et al. 2008; unpublished report of the LIFE4BEST project (020–M37, Conservation of Madeira's Threatened Endemic Butterflies - Stichting Butterfly Conservation Europe, 2022); and 12 in the Azores, following the most recent archipelago-wide synthesis, adopting the nomenclature and occurrence/status treatment compiled in the updated Azorean arthropod checklist of Borges et al. (2022).

The Papilionoidea of Portugal include a strong component of widespread Mediterranean elements, and a smaller component of Temperate-optimum species limited to the northern areas or mountainous terrain. Although no butterfly species is endemic to mainland Portugal, a relatively high proportion of the fauna is comprised of Iberian and Atlanto-Mediterranean endemic taxa, whose restricted ranges require coordinated conservation across Portugal, Spain and neighbouring countries. Such are the cases of flagship Atlanto-Mediterranean species as *Zerynthia rumina* (Linnaeus, 1758), *Iphiclides feisthamelii* (Duponchel, 1832), *Euchloe tagis* (Hübner, 1804), *Melitaea aetherie* (Hübner, 1826), or *Lycaena bleusei* (Oberthür, 1884). On the other hand, several of the insular Macaronesian taxa are endemic. Paramount examples of these are the Azorean and Madeiran Large White populations (*Pieris brassicae azorensis* Rebel 1917 and *Pieris (b.) wollastoni* Butler 1886, respectively, the latter potentially already extinct), the Azorean radiation of the *Hipparchia azorina* group and counterparts to continental species as are *Pararge xiphia* (Fabricius 1775) and *Gonepteryx maderensis* Fields 1872, both from Madeira.

European butterflies are among the best-studied insect groups, benefit from wide public interest and have long been studied. Their taxonomy, monitoring and conservation are more advanced than other key pollinator groups and they are also at the forefront of molecular research and conservation, being keystone pollinators in genome-wide advances (Wright et al. 2025; Beldade et al., 2026). Notwithstanding, butterfly taxonomy in southern Europe and particularly in Portugal, remains dynamic with recent studies substantially revising our understanding of the regional fauna (e.g., Hernández-Roldán et al., 2016; Dincă et al., 2021; Marabuto et al., 2023).

This checklist adopts a detailed taxonomic treatment for the Macaronesian archipelagos, where geographically restricted endemic taxa occur. In contrast, a simplified treatment is used for mainland Portugal, where only the parental species is kept even where the local form differs from

the nominate taxon (e.g., *Euphydryas aurinia beckeri* is the sole occurring taxon of the *E. aurinia* complex in Portugal), or where multiple subspecies occur within the Portuguese mainland (e.g., *Euchloe tagis*). This distinction reflects both the conservation relevance and geographic isolation of Macaronesian endemic taxa, whereas recognising mainland infraspecific variation would add complexity without improving the checklist's utility for monitoring rather than comprehen sive taxonomic revision.

FAIRness and interoperability

To ensure FAIRness and seamless reuse in GBIF and EU aggregation workflows, the Portuguese pollinator checklist is provided as a Darwin Core Archive (DwC-A) (Appendix 1) using a Taxon core (one row per taxon concept) complemented by a Distribution extension (one row per taxon × geographic unit). This structure follows the Darwin Core vocabulary and GBIF IPT guidance for checklist publication (see (Wieczorek et al. 2012))., and it allows both (i) a single, stable taxonomic backbone and (ii) an explicit, machine-readable statements of presence and establishment status across Portugal mainland, the Azores and Madeira, and individual islands.

In the Darwin Core Taxon core (primary checklist table; Appendix 1), we include the following identifiers and taxonomic backbone fields: taxonKey (a stable internal identifier for each taxon concept, persistent across versions), scientificName (full scientific name), scientificNameAuthorship, the higher taxonomic classification fields kingdom, phylum, class, order, family, subfamily, genus, and subgenus (when applicable), as well as specificEpithet and infraspecificEpithet (when applicable), taxonRemarks (brief flags, e.g., “complex”, “ID difficult”, “needs revision”), together with nomenclaturalCode (e.g., ICZN), dynamicProperties (including "iucnStatus").

In Appendix 2, we provide a distribution extension (taxon × geography statements) table to encode where each taxon occurs (mainland, archipelagos, islands) and how it is established, in a way that remains interoperable and filterable across systems. We encode geographic units in a fully machine-readable way using country (Portugal), countryCode (PT), stateProvince (standardised reporting partitions such as “Portugal mainland”, “Azores” and “Madeira”), islandGroup (Azores or Madeira, where relevant), island (individual island name when resolved to island level), an optional controlled locality label for reporting units [e.g., “Mainland”, “Azores (archipelago-wide)”, “Madeira (archipelago-wide)”], locationID with stable codes for each reporting unit (e.g., PT-ML, PT-AZ, PT-MA and island codes); for policy-relevant status we include establishmentMeans (e.g., “native”, “introduced”, “endemic", “uncertain”), degreeOfEstablishment (“native”, “captive”, “cultivated”, “released”, “failing”, “casual”, “reproducing”, “established”, “colonising”, “invasive”, “widespreadInvasive”), occurrenceRemarks to flag record-level uncertainty, deletions or special cases (e.g., “single historical record”, “needs confirmation”, “migrant”, “vagrant”, “deleted”, and/or any other relevant notes associated with the species records).

The distribution of all species and subspecies by island uses the following abbreviations for Azores: COR – Corvo; FLO – Flores; FAI – Faial; PIC – Pico; GRA – Graciosa; SJG – São Jorge; TER – Terceira; SMG – São Miguel; SMR – Santa Maria. For the the Madeira and

Selvagens archipelagos it is presented using the following abbreviations: M – Madeira; PS – Porto Santo; D – Desertas; S – Selvagens.

Monitoring-ready species framework: from checklist to an operational tool

To translate the national checklist into a tool that practitioners can implement consistently, we organised species into a three-tier monitoring framework that aligns with field feasibility, indicator value, and policy needs (Appendix 3).

Tier 0 comprises taxa that are excluded from routine monitoring because they are accidental, irregular, extinct, or otherwise unsuitable for inclusion in a standard monitoring scheme because they are either too similar to other species or not suitable bioindicators.

Tier 1 (Core monitoring set) comprises common and widespread species that are reliably detected and identified with standard protocols and provide strong, scalable indicators of community change across landscapes, in space and time.

Tier 2 (Extended set) includes habitat specialists and taxa expected to be particularly sensitive to restoration actions, but which typically require greater taxonomic skill, targeted sampling windows or higher effort to achieve robust detections.

Tier 3 (Priority conservation set) covers threatened, range-restricted or otherwise rare taxa for which general surveillance may be insufficient. These species require targeted protocols (often site-specific) and are best treated as conservation priorities rather than routine trend indicators.

Species assignment to tiers was based on a transparent scoring scheme drawing on the authors' expertise and combining (i) detectability and identification feasibility under realistic field conditions, (ii) phenology window and temporal coverage needed to sample the taxon adequately, (iii) habitat association and the degree of specialisation, (iv) taxonomic stability (including known species complexes and groups needing taxonomic revision), (v) restoration sensitivity (expected responsiveness to habitat quality and management), and (vi) policy relevance, including conservation status from global, European and nacional IUCN Red List assessments, where available, and alignment with EU pollinator monitoring objectives.

This method of progressive identification of tiers, with increasing levels of taxonomic specificity, sampling requirements and conservation relevance, is designed to maximise comparability and reporting utility while remaining feasible for long-term implementation at the national scale. Tier assignments will be reviewed periodically by relevant taxonomic expert groups and updated through versioned checklist releases, with all changes documented in a transparent record of revisions to ensure traceability and comparability, while maintaining an up-to-date tool to support long-term policy implementation.

Results

Diversity patterns

Bees - Anthophila

The richest of the three focal pollinator groups in Portugal, Anthophila currently comprise 746 species from all 5 European taxonomic families. Richness is strongly concentrated in mainland Portugal, where 736 species are currently listed, reflecting the large environmental heterogeneity of the western Iberian Peninsula, its Atlantic–Mediterranean gradients and its role within a major southern European refugial region. The island faunas are much smaller, with 19 species reported from Azores and 24 from Madeira, yet they remain important for monitoring because they include distinct Macaronesian assemblages shaped by isolation, colonisation history and local ecological filtering. Conservation status wise, we acknowledge one species as Critically Endangered, eight are Endangered and seven are Vulnerable, all of them from the mainland.

Hoverflies - Syrphidae

Syrphids are represented by 232 species, belonging to four subfamilies and 67 genera. Mainland Portugal supports the highest species diversity, with 223 species, reflecting, as sated above, the country's environmental heterogeneity and its Iberian biogeographic context. The hoverfly fauna of the archipelagos is comparatively species-poor, with 24 species reported from the Azores and 26 from Madeira. Nevertheless, the Macaronesian elements of Portugal include an important endemic component that is absent from the mainland (three endemic species in the Azores and four in Madeira). No non-native syrphids have been documented in Portugal to date, either on the mainland or the archipelagos. Most species featured on the checklist currently have a conservation status classification of Least Concern (171 species). However, the checklist also features 25 species classified as Endangered, as well as 12 Vulnerable and 19 Near Threatened species. The relatively high (almost a third of the total) representation of taxa with concerning conservation status highlights the importance of long-term pollinator monitoring initiatives and the promotion of conservation and restoration of the habitats on which these species depend.

Butterflies - Papilionoidea

Portuguese Papilionoidea comprise 151 accepted taxa, distributed across six families. Nymphalidae is the richest, with 72 taxa, followed by Lycaenidae (37), Pieridae (19), Hesperiidae (18), Papilionidae with three and Riodinidae with one. Mainland Portugal contains the highest number of accepted taxa (140), reflecting its larger area, continental connection, strong Atlantic–Mediterranean environmental gradients and Iberian biogeographic context, whereas the island faunas are smaller but include a proportionally important endemic component, with 12 taxa in the Azores and 18 in Madeira. Most taxa are classified as native, but the checklist also distinguishes endemic, migrant, vagrant, naturalised, and uncertain taxa, providing an operational baseline for monitoring and reporting. Conservation-status information indicates that most taxa are currently classified as Least Concern, but the checklist also includes one extinct taxon, two Endangered, four Vulnerable and 13 Near Threatened taxa.

Monitoring species framework (“operational monitoring list”)

Building on the core species list (Appendix 1) and their spatial distribution (Appendix 2), Appendix 3 presents a monitoring-ready framework that translates taxonomic knowledge into an operational tool for practitioners.

The bee monitoring-tier dataset shows that Anthophila is the most complex group for operational monitoring. In mainland Portugal, 736 taxa were assessed, of which 663 were assigned to at least one monitoring tier and 73 were placed in Tier 0. Only 39 mainland taxa were included in Tier 1, whereas 653 were included in Tier 2 and 101 in Tier 3, indicating that most bee taxa require extended sampling, expert validation or targeted survey conditions. In the Azores, 18 out of the 19 taxa were assigned to Tiers 1–3, with 13 Tier 1 taxa, 15 Tier 2 taxa and one Tier 3 taxon. In Madeira, 17 out of the 24 taxa were assigned to Tiers 1–3, including 11 Tier 1 taxa, 15 Tier 2 taxa and nine Tier 3 taxa. These patterns highlight the contrast between the very diverse and taxonomically demanding mainland bee fauna and the smaller island faunas, where a larger proportion of species can be readily integrated into routine and extended monitoring.

Table 1. Description of Tiers in Appendix 3. Note: Counts are territory-level taxon records. A taxon occurring in more than one territory may be counted more than once across territories.

Field	**Description**
Tier 1 only	Taxa assigned only to the core monitoring set.
Tier 2 only	Taxa assigned only to the extended monitoring set.
Tier 3 only	Taxa assigned only to the priority conservation set.
Tier 1 + Tier 2	Taxa assigned simultaneously to core and extended monitoring categories.
Tier 1 + Tier 3	Taxa assigned simultaneously to core and priority conservation categories.
Tier 2 + Tier 3	Taxa assigned simultaneously to extended monitoring and priority conservation categories.
Tier 1 + Tier 2 + Tier 3	Taxa assigned to all three monitoring categories.
Tier 0 only	Taxa not currently recommended for routine monitoring at this stage.

In mainland Portugal, all 223 syrphid taxa were assessed and most of them (151) were placed in Tier 0. Most Tier 0 species are difficult to identify (or easily confused with other mainland species), lack strong habitat specialisation, and are not currently protected. Limited ecological information for several species also contributed to their placement in Tier 0.

Regarding Azores and Madeira, the situation is less severe, with only 7 (of 26) and 6 (of 24) species being placed in Tier 0, respectively. The large proportion of Tier 0 species highlights the need to improve taxonomic and ecological knowledge of mainland hoverflies of the remaining species in mainland Portugal, 44 were placed in Tier 1 while 21 were placed in Tier 2 and 22 in

Tier 3, totalling 32 species outside of Tier 1 and Tier 0. These numbers indicate that a large proportion of mainland syrphids may require specific sampling protocols on targeted sampling sites, as well as verification of species identification by experts. In sharp contrast with mainland results, most species of the archipelagos were placed in Tier 1 (19 from Azores, 18 from Madeira). In the Azores, 4 species were placed in Tier 2 and 3 in Tier 3 and in Madeira, 9 species were placed in Tier 2 while 3 were put in Tier 3. These results highlight the contrast between mainland Portugal and the Macaronesian archipelagos: in continental Portugal, due to its relatively higher species diversity, many species might require special attention, while on the islands, which are smaller and relatively less biodiverse, species identification and monitoring may be accomplished with relative ease.

The butterfly monitoring-tier framework reflects the comparatively mature taxonomic knowledge and well-established monitoring methods available for this group. In mainland Portugal, 74 taxa were assigned to Tier 1, 72 to Tier 2 and 26 to Tier 3, while only 18 taxa were placed in Tier 0. The large number of Tier 1 species indicates that a substantial proportion of the mainland butterfly fauna can be incorporated into routine monitoring using standard survey protocols. The similarly high number of Tier 2 taxa highlights the importance of habitat specialists and species requiring increased survey effort because of narrow phenological windows, identification challenges, or unresolved biological and taxonomic questions. These results also emphasise the need for further applied studies to improve knowledge of the biology and differentiation of key taxa. The 26 taxa in Tier 3 comprise species of particular conservation concern that require targeted monitoring approaches. In the Azores 8 taxa were assigned to Tier 1, 7 to Tier 2 and 4 to Tier 3, with only 2 taxa in Tier 0, whereas in Madeira, 6 taxa were assigned to Tier 1, 11 to Tier 2 and 6 to Tier 3, with 4 taxa placed in Tier 0. Compared with bees and mainland hoverflies, butterflies show a much smaller proportion of taxa excluded from routine monitoring (Tier 0), reflecting their comparatively stable and accessible taxonomy, extensive biological knowledge and the operational feasibility of monitoring most Portuguese butterfly species using standardised protocols.

Discussion

A national taxonomic backbone for pollinator monitoring

This study provides the first taxonomically curated and monitoring-oriented checklist integrating bees, hoverflies and butterflies across mainland Portugal, the Azores and Madeira. Its importance extends beyond documenting national species richness. By standardising taxonomic concepts, geographic reporting units, occurrence status and monitoring relevance, the checklist establishes a common reference against which future observations and temporal changes can be interpreted. This role is particularly important because European pollinator occurrence data remain fragmented and uneven among countries and taxonomic groups, limiting both national assessments and comparisons across Europe (Reverté et al., 2023). Recent Iberian-scale analyses have also shown that conservation-relevant richness patterns differ substantially among arthropod groups and that broad, spatially explicit databases are needed to identify priority areas that single-taxon approaches may overlook (Sánchez-Fernández et al., 2026).

The checklist documents 1,135 taxa among the three focal pollinator groups and captures the pronounced biogeographic contrast between mainland Portugal and the Macaronesian archipelagos. Mainland Portugal contains most of the national richness, reflecting its larger area, environmental heterogeneity and position within the Iberian Peninsula. The Azores and Madeira support smaller assemblages, but include endemic, geographically restricted and conservation-priority taxa whose national and global conservation responsibility is disproportionately high. Treating mainland Portugal, the Azores and Madeira as explicit reporting units is therefore essential: national totals alone would conceal major differences in species composition, monitoring feasibility and conservation need.

The checklist should also be understood as a dynamic taxonomic backbone rather than a static inventory. Taxonomic concepts, nomenclature, distributional knowledge and conservation status will continue to change as museum collections are revised, new records are validated and molecular studies resolve difficult species complexes. Versioned releases, stable taxon identifiers and transparent documentation of additions, exclusions and nomenclatural changes are consequently central to the long-term value of the resource. This approach allows monitoring data collected at different times to remain interpretable even when the underlying taxonomy is revised, while ensuring that national reporting can be updated without losing traceability.

Contrasts among pollinator groups and territories

The marked differences among the three focal groups demonstrate that a single monitoring strategy would be inappropriate. Bees account for most of the Portuguese pollinator fauna and represent the greatest taxonomic and operational challenge. The large number of mainland bee taxa assigned to the extended and priority tiers indicates that many species require increased sampling effort, specialist identification, targeted survey periods or expert validation. This does not diminish their value for monitoring; rather, it shows that their inclusion must be matched by realistic investment in taxonomic capacity, reference collections and quality-control procedures.

Mainland hoverflies present a different but equally important constraint. A large proportion of taxa were assigned to Tier 0 because they are difficult to identify, easily confused with related species, poorly known ecologically or not yet suitable for routine indicator use. Tier 0 should not be interpreted as evidence that these species are unimportant. Instead, it identifies a current knowledge and implementation gap. Improved identification resources, ecological studies and expert training may allow many of these taxa to be reassigned in future versions of the framework. By contrast, a comparatively high proportion of butterflies can be incorporated into routine monitoring, reflecting their more stable taxonomy, established field methods and wider availability, and easier applicability of identification resources. Even in this comparatively well-known group, however, habitat specialists, taxa with restricted phenological windows and conservation-priority species still require extended or targeted approaches.

The mainland and archipelagic faunas also require different monitoring priorities. Whilst mainland Portugal combines high richness with strong environmental heterogeneity and therefore demands a spatially representative design with sufficient replication to estimate national trends, the Azores and Madeira contain fewer species, making a larger proportion of their faunas potentially accessible to routine monitoring, but this apparent operational simplicity should not obscure their conservation importance. Endemic and range-restricted island taxa may occur at

few sites, have small populations or respond to pressures that are not captured by broad surveillance. Routine trend monitoring in the archipelagos should therefore be complemented by island-specific and species-specific protocols for endemic, threatened and potentially declining taxa.

These contrasts justify the proposed tiered framework as a mechanism for allocating effort rather than ranking biological importance. Tier 1 supports scalable community-level monitoring; Tier 2 directs additional effort towards specialists, restoration-sensitive taxa and species requiring greater identification expertise; and Tier 3 identifies taxa for which targeted conservation monitoring is necessary. The framework is particularly informative for Anthophila because bees are the most species-rich and taxonomically demanding group, but its broader value lies in making differences among taxa explicit and operational. Periodic revision will be essential as taxonomic knowledge, distributional data and identification capacity improve.

From monitoring tiers to PT-PoMS implementation

The EU Nature Restoration Regulation creates a direct policy need for robust and repeatable evidence on pollinator abundance and species richness. Article 10 of Regulation (EU) 2024/1991 requires Member States to reverse pollinator decline, while the European Pollinator Monitoring Scheme provides the scientific basis for harmonised implementation (European Union, 2024; Potts et al., 2021, 2024). In Portugal, the proposed Portuguese Pollinator Monitoring Scheme (PT-PoMS) offers the institutional setting in which the checklist and monitoring tiers can be translated into practice. The present framework provides the taxonomic and biogeographic foundation needed to interpret field observations consistently and to connect national monitoring with EU-level reporting.

The monitoring tiers provide a practical bridge between the checklist and field implementation. Tier 1 taxa can contribute to standardised estimates of community change and broad population trends. Tier 2 taxa require additional effort, narrower sampling periods, complementary methods or specialist validation, but may provide particularly informative signals of habitat condition and restoration response. Tier 3 taxa should be addressed through targeted conservation protocols because their rarity, restricted distributions or threatened status make them unlikely to be represented adequately by general surveillance. Tier 0 is best regarded as a provisional operational category: taxa may enter routine or extended monitoring as knowledge, identification tools and sampling methods improve.

A national scheme should be spatially representative, repeatable through time and capable of covering the Atlantic and Mediterranean environments of mainland Portugal as well as the Azores and Madeira. A probabilistic and stratified design linked to the LUCAS grid provides a practical basis for selecting sites while maintaining compatibility with the refined European scheme (Eurostat, 2021; Potts et al., 2024). Sampling locations and effort should remain as stable as possible among years, and any site replacement should follow predefined criteria that preserve network representativeness. Temporal coverage must also reflect regional phenology. The proposed activity periods—from March to October in mainland Portugal and Madeira and from April to September in the Azores, with repeated visits across the season—are intended to capture turnover among early-, mid- and late-season species while controlling for weather-related variation in detectability.

Because bees, hoverflies and butterflies differ in detectability, phenology, habitat use and taxonomic difficulty, complementary monitoring methods will be necessary. Standardised fixed transects and active capture can provide the core observations for the three focal groups, while species-specific protocols are needed for rarer and threatened taxa. Complementary modules such as random transects with flight interception sampling can generate fast and broad assessment of existing species, providing a stronger reference for the regular transects and also for molecular dependent methods that decrease dependency on identification capacity. Citizen-led monitoring can increase geographic coverage and public engagement, but should complement rather than replace the statistically designed core network. Its contribution will depend on clear protocols, appropriate training, voucher-based documentation where necessary, expert verification and transparent separation of verified and unverified records.

Taxonomic capacity is therefore a central implementation requirement rather than an ancillary concern. Reliable species-level monitoring depends on trained taxonomists and parataxonomists, accessible reference collections, current identification resources and documented validation workflows. Investment should distinguish the minimum capacity required to operate the scheme from the more ambitious capacity needed to include taxonomically difficult and conservation-priority taxa. Regular reporting should then connect monitoring outputs to restoration decisions, allowing methods and management interventions to be adjusted as evidence accumulates. In this sense, successful implementation is not only a sampling challenge but a long-term institutional commitment to taxonomy, training, data management and adaptive conservation

FAIR data infrastructure and long-term governance

The checklist should form the taxonomic component of a broader FAIR e-infrastructure supporting PT-PoMS. Such a system would integrate three connected layers: a versioned national checklist with explicit territorial distribution and establishment-status statements; an event-based repository linking standardised sampling events to occurrence, abundance and contextual environmental information; and a reproducible reporting layer capable of generating national and EU-compatible trend indicators. This architecture would convert the present appendices from static supporting files into maintained, citable resources and would allow restoration outcomes to be evaluated against consistent national baselines.

The event-centric and FAIR-by-design approach proposed for BioMonI-PLOTS provides a useful model for this integration (Borges et al., 2026). The checklist could be published through a Taxon core and Distribution extension, while monitoring observations would be organised around stable sampling-event identifiers and linked occurrence or abundance records. Persistent taxonKey, locationID and eventID values would maintain the relationships among taxonomic concepts, reporting units and repeated visits. Packaging these components as versioned Darwin Core Archives and disseminating them through a GBIF IPT workflow would improve interoperability, traceability and reuse across institutions and reporting cycles.

Technical interoperability alone, however, will not guarantee continuity. Long-term governance should assign clear responsibilities for checklist curation, data management, validation, release approval and liaison with conservation authorities. Taxonomic curators for bees, hoverflies and butterflies should oversee name resolution, taxonomic-status decisions and revision notes, while a data-management team should maintain templates, controlled

vocabularies, validation routines, versioning and publication workflows. Automated quality control can identify incomplete metadata, duplicated identifiers, coordinate problems and vocabulary inconsistencies, but taxonomic and biogeographic outliers will continue to require specialist review. This combination of automation and expert curation is especially important for rare species, new territorial records and taxonomically difficult groups.

Experience from established monitoring programmes supports this combined architecture of curated taxonomy, standardised field methods and sustained data publication. The UK Pollinator Monitoring Scheme emphasises that analytical value increases as repeated survey years accumulate, reflecting the fundamental importance of long-term time series (Breeze et al., 2021). The European Butterfly Monitoring Scheme demonstrates how standardised transects can scale from local routes to national indicators and cross-country assessments (van Swaay et al., 2008; Sevilleja et al., 2020; van Swaay et al., 2025). Similarly, proposals for a coordinated national bee monitoring programme in the United States stress the need to accommodate high natural variability while retaining methodological rigour and comparability across space and time (Woodard et al., 2020). For Portugal, the checklist, tier framework and e-infrastructure should therefore be treated as mutually dependent components of a single enduring knowledge system.

Limitations, priorities and policy relevance

Several limitations should be recognised. First, the checklist covers the three principal daytime groups targeted by the European Pollinator Monitoring Scheme but does not yet include moths. Their future incorporation will require improved national distributional knowledge and dedicated nocturnal monitoring protocols. Second, taxonomic and ecological knowledge remains uneven among groups and territories, particularly for mainland bees and hoverflies and for the island-level distribution of some taxa. Third, the tier assignments combine available evidence with expert judgement and should therefore be regarded as an initial operational classification rather than a fixed designation. Their performance should be tested against field data and revised as monitoring experience accumulates.

The framework also depends on assumptions that can only be evaluated through long-term implementation. The detectability of many taxa, the adequacy of proposed seasonal coverage and the capacity of the tiers to distinguish broad trends from restoration responses remain to be assessed through a sustained national time series. Taxonomic change, newly established species and climate-driven shifts in distribution will require regular checklist updates. Moreover, data deficiency will remain a systematic obstacle unless taxonomy, digitisation, spatially explicit reporting and monitoring of lesser-known groups receive stable institutional and financial support (Hochkirch et al., 2021).

Despite these limitations, the checklist provides an immediately usable foundation for implementing PT-PoMS and meeting the monitoring obligations associated with the EU Nature Restoration Regulation. Its long-term value will depend on maintaining it as a versioned resource, strengthening national taxonomic capacity and connecting standardised field observations to an open and interoperable data infrastructure. The Nature Restoration Regulation has been identified as a major emerging opportunity for European wild pollinators, but its effectiveness will ultimately depend on implementation through scientifically credible monitoring, restoration action and transparent reporting (Morrison et al., 2026).

By linking taxonomic knowledge, territorial distribution, monitoring feasibility and conservation priority, the framework presented here can support robust trend assessment across mainland Portugal, the Azores and Madeira. It also creates a transparent basis for evaluating restoration outcomes, identifying where additional expertise or targeted surveys are required, and revising priorities as new evidence becomes available. The principal contribution of the checklist is therefore not only to document Portugal's pollinator diversity, but to provide the durable taxonomic, operational and digital foundation needed for adaptive pollinator conservation under national and European restoration policy

Authors Credit

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