

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

Regulation

Title in Alternative Languages (Portuguese): Lista nacional para a monitorização dos polinizadores de Portugal (Anthophila, Syrphidae e Papilionoidea) no âmbito do Regulamento Europeu do Restauro da Natureza

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A Checklist for Pollinator Monitoring

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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 monitor pollinator abundance and species richness. Effective implementation depends on robust national taxonomic baselines defining which species are present, where they occur, and how they can be monitored consistently.
2. We present a policy-oriented national checklist of insect pollinators in Portugal, covering three focal groups of the European Pollinator Monitoring Scheme: bees (Hymenoptera: Anthophila), hoverflies (Diptera: Syrphidae) and butterflies (Lepidoptera: Papilionoidea). The checklist covers mainland Portugal, the Azores and Madeira, combining published sources, updated nomenclature, distribution and monitoring-relevant status fields in a FAIR, Darwin Core-compatible framework, with all records reviewed by experts.
3. The checklist highlights the exceptional richness and conservation relevance of the main Portuguese pollinator groups, comprising 1,129 taxa. Bees are the richest group, with 746 taxa (mainland: 736, Azores: 19, Madeira: 24), followed by hoverflies with 233 taxa (mainland: 224, Azores: 25, Madeira: 26) and butterflies with 150 taxa (mainland: 138, Azores: 11, Madeira: 20).
4. We propose a monitoring framework distinguishing core monitoring taxa, extended monitoring taxa and priority conservation taxa. This framework recognises differences in detectability, taxonomic difficulty, habitat specialisation, restoration sensitivity and conservation relevance.

5. Integrating taxonomic curation, territorial distribution, monitoring tiers and FAIR data principles provides an operational reference for the Portuguese Pollinator Monitoring Scheme, supporting the implementation of EU restoration targets and providing a traceable baseline for future updates, long-term trend assessment and adaptive conservation planning.

Abstract in Alternative Languages (Portuguese):

1. O declínio dos polinizadores selvagens na Europa tem reforçado a necessidade de medidas coordenadas de conservação e monitorização. O Regulamento Europeu do Restauro da Natureza exige que os Estados-Membros revertam o declínio dos polinizadores e monitorizem a sua abundância e riqueza específica. No entanto, a implementação eficaz destas medidas depende de bases taxonómicas nacionais robustas que definam quais as espécies presentes, onde ocorrem e como podem ser monitorizadas de forma consistente.

2. Neste trabalho, apresentamos uma lista nacional dos insetos polinizadores de Portugal, orientada para apoiar a implementação de políticas públicas, abrangendo três grupos focais do Esquema Europeu de Monitorização de Polinizadores: abelhas (Hymenoptera: Anthophila), sirfídeos (Diptera: Syrphidae) e borboletas diurnas (Lepidoptera: Papilionoidea). A lista abrange Portugal continental e os arquipélagos dos Açores e da Madeira, combinando publicações faunísticas, nomenclatura atualizada, distribuição e categorias de conservação relevantes para a monitorização, numa estrutura FAIR compatível com Darwin Core, com todos os registos revistos por especialistas.

3. A lista evidencia a excecional riqueza e relevância para a conservação dos principais grupos de polinizadores portugueses, compreendendo 1.129 taxa. As abelhas constituem o grupo mais rico, com 746 taxa (continente: 736, Açores: 19, Madeira: 24), seguidas pelos sirfídeos com 233 taxa (continente: 224, Açores: 25, Madeira: 26) e pelas borboletas com 150 taxa (continente: 138, Açores: 11, Madeira: 20).
4. Adicionalmente, propomos uma estrutura de monitorização que distingue taxa de monitorização de referência, taxa de monitorização alargada e taxa prioritários para a conservação. Esta estrutura reconhece diferenças entre os grupos de polinizadores quanto à detetabilidade, à dificuldade taxonómica, à especialização do habitat, à sensibilidade ao restauro e à relevância para a conservação.
5. A integração da informação taxonómica, distribuição territorial, níveis de monitorização e princípios FAIR fornece uma referência operacional para o Programa de Monitorização de Polinizadores de Portugal, apoiando a implementação nacional das metas europeias de restauro da natureza e disponibilizando uma base documentada para futuras atualizações, avaliação de tendências a longo prazo e planeamento de medidas adaptativas de conservação.

KEYWORDS

FAIR data, pollinator checklist, Portuguese Pollinator Monitoring Scheme, taxonomic backbone

INTRODUCTION

Long-term, standardised monitoring is essential for distinguishing sustained ecological change from natural year-to-year fluctuations and for evaluating restoration outcomes rather than effort alone (Borges et al., 2018; Stephenson et al., 2022). This is particularly important for pollinators, whose populations fluctuate strongly among years and are affected by multiple interacting pressures, including land-use change, pesticide exposure, invasive species, disease and climate change (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 units (Biesmeijer et al., 2006; Carvalheiro et al., 2013). However, without standardised and repeatable datasets, it becomes difficult to separate restoration signals from background variability, detect early warnings of network-level change, compare interventions across landscapes, or assess whether policy targets are being met. Monitoring programmes should therefore be built around stable sampling units, documented effort, consistent protocols and interoperable data systems capable of supporting robust trend estimates over time.

Insect pollinators are key components of terrestrial 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, 2019; Ollerton et al., 2011; Potts et al., 2010; 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 work on European wild pollinators has identified the Regulation as a major opportunity for pollinator conservation, as Article 10 establishes legally binding obligations to reverse pollinator decline and to monitor pollinator populations 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 besides the Iberian Peninsula also includes Macaronesian archipelagos (Kass et al., 2022; Myers et al., 2000). 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 diversity can be further explained by the relative climatic stability and environmental heterogeneity of the Iberian Peninsula throughout the Pleistocene glacial cycles, which contributed to its role as one of the main southern European refugia. These conditions favoured long-term persistence of lineages, local diversification, adaptation and the emergence of endemic taxa (Hewitt, 2004). Recent Iberian-scale arthropod prioritisation also shows that spatial patterns of conservation importance differ markedly among taxa, reinforcing the need for broad, spatially explicit biodiversity baselines (Sánchez-Fernández et al., 2026). In parallel, the Macaronesian archipelagos 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 the Selvagens Islands), and climatic buffering have allowed the persistence of ancient Tertiary lineages alongside extensive *in situ* diversification, resulting in 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 Portuguese Action Plan for Pollinator Conservation and Sustainability (Ministry of Environment and Energy, 2026). In line with the commitments assumed by EU Member States, the action plan includes ecosystem restoration measures and proposes a Portuguese 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-based monitoring tools. These include taxonomically curated checklists and baseline data that can be applied consistently across landscapes and reported transparently to support adaptive management.

A 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 wild pollinators, covering bees, hoverflies and butterflies, the three focal groups of the European Pollinator Monitoring Scheme. The checklist integrates updated nomenclature, occurrence-status information, monitoring-relevant descriptors and distribution data for mainland Portugal, the Azores and Madeira, and 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 territory, encompassing mainland Portugal and the two autonomous Atlantic archipelagos of the Azores and Madeira (Figure 1). This national coverage across continental and oceanic-island biogeographical contexts provides a comprehensive basis for understanding Portuguese pollinator diversity and supports

its monitoring and conservation (Castro & Loureiro, 2025). Three main biogeographical regions are thus covered by this work: the Atlantic (northwestern mainland Portugal), the Mediterranean (most of mainland Portugal) and the Macaronesian regions (Azores and Madeira).

Mainland Portugal 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 mainland Portugal (1993 m a.s.l.) (Figure 1b). 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 (Figure 1c). The Madeira archipelago lies in the North Atlantic, approximately 600 km away from the coast of North Africa, at around 32.7° N, 17.0° W. It comprises two main islands (Madeira and Porto Santo) and several smaller islands (including the Desertas 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 wide range of habitats (Figure 1d).

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 represent three of the focal pollinator groups of the European Pollinator Monitoring Scheme and are key taxa targeted by harmonised monitoring under the EU Nature Restoration Regulation (European Commission, 2025). All three groups have also been subject to

extensive revision within the ARCADE project. Although the European Pollinator Monitoring Scheme also includes moths because of their increasingly recognised importance as nocturnal pollinators (Macgregor & Scott-Brown, 2020), their inclusion in this framework remains under development.

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

The checklist of bees, hoverflies and butterflies (Appendix 1) includes the most recent published taxonomic assessments, online biodiversity datasets, and revisions of museum collections conducted within the framework of the ARCADE project. It will be maintained as a versioned Darwin Core-compatible resource, with periodic expert review and a changelog documenting all additions, exclusions, nomenclatural changes, distributional revisions 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.

Taxonomic baseline

Bees (Anthophila)

277 The Anthophila fauna has benefited from substantial advances in taxonomic knowledge at the
278 European level over the last five years. These advances have been essential for resolving long
279 standing taxonomic problems in several genera, updating existing checklists, describing species,
280 and producing identification tools and training resources through multiple EU-funded projects.
281 At the national level, the largest existing collections are being revised (Baptista et al., 2026;
282 Gaspar et al., 2025), and extensive exploratory sampling is being conducted.

283 In mainland Portugal, the first comprehensive checklist was published in 2018 (Baldock et
284 al., 2018), compiling many internationally held records and all previously published works (mostly
285 locally and/or taxonomically limited). Since then, 80 species have been added and 24 species
286 removed, raising the mainland checklist to 736 species, following the revision of the large
287 historical collection at the Science Museum of the University of Coimbra in 2025 (Gaspar et al.,
288 2025), and a further update based on the collection of the National Museum of Natural History
289 and Science of the University of Lisbon in 2026 (Baptista et al., 2026), while also incorporating
290 recent nomenclatural changes (Ghisbain et al., 2025). The mainland fauna comprises around 75
291 species endemic to the Iberian Peninsula, as well as around 15 North African species whose
292 European distribution is restricted to the Iberian Peninsula. Only one species is considered
293 endemic to mainland Portugal: *Colletes dinizi* Kuhlmann, Ortiz & Ornos, 2001. Additionally,
294 Portugal hosts two bee genera endemic to Europe, *Flavipanurgus* and *Halopanurgus*,
295 representing two of the three European endemic bee genera, all of which are restricted to the
296 Iberian Peninsula.

297 The most consolidated taxonomic published baseline for Azorean bees was provided by
298 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 syntheses and updates within the broader updated checklist of Azorean arthropods (Boieiro et al., 2024; Borges et al., 2022), fixing the number of species at 19. The Azores archipelago harbours a single endemic species, *Hylaeus azorae* (Warncke, 1992). 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). Although recent studies and species lists have considerably improved our knowledge of the bee fauna of the archipelago, information on species occurrence and distribution remains incomplete, particularly for some islands and island groups. The Madeira archipelago supports eight endemic species, representing approximately one third of its known bee fauna.

Hoverflies (Syrphidae)

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 mainland 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 European species list by country was provided in Reverté et al. (2023), incorporating 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, *Sphaerophoria nigra* Frey, 1945 and *Xanthandrus azorensis* Frey, 1945. However, there are still considerable knowledge gaps in the distribution of Syrphidae among the Azorean islands, and reports of several species from 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, representing the most recent local assessment of the family Syrphidae.

Butterflies (Papilionoidea)

Portugal supports a moderately rich butterfly fauna (Papilionoidea). Across the mainland and the Atlantic archipelagos, more than 150 Papilionoidea taxa are known, of which 147 are recognized

at species level, distributed across six families: Papilionidae (swallowtails), Pieridae (whites and yellows), Lycaenidae (blues and hairstreaks), Nymphalidae (brush-footed butterflies), HesperIIDae (skippers), and Riodinidae (metalmarks). Whilst mainland Portugal harbours 138 butterfly species (Corley, 2015; Maravalhas, 2003; this work), the archipelagos support fewer taxa but include a unique assemblage of palaeotropical elements, temperate dispersalists and narrow island or Macaronesian endemics: 18 taxa in the Madeira archipelago (Borges et al. 2008; unpublished report from 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 synthesis for the archipelago, with nomenclature and colonization status categories compiled in the updated Azorean arthropod checklist (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 comprises Iberian and Atlanto-Mediterranean endemic taxa, whose restricted ranges require coordinated conservation across Portugal, Spain and neighbouring countries. Examples include flagship Atlanto-Mediterranean species such as *Zerynthia rumina* (Linnaeus, 1758), *Iphiclides feisthamelii* (Duponchel, 1832), *Euchloe tagis* (Hübner, 1804), *Melitaea aetherie* (Hübner, 1826), and *Lycaena bleusei* (Oberthür, 1884). In the Macaronesian archipelagos, several island taxa are endemic. Notable examples include the Azorean and Madeiran Large White populations [*Pieris brassicae azorensis* Rebel 1917 and *Pieris* (*b.*) *wollastoni* Butler 1886, respectively, the latter recently assessed as Extinct on the IUCN Red List in 2025], the Azorean radiation of the *Hipparchia azorina* group and island counterparts of

continental species, such as *Pararge xiphia* (Fabricius 1775) and *Gonepteryx maderensis* Fields 1872, both from Madeira.

European butterflies are among the best-studied insect groups and benefit from widespread public interest. Their taxonomy, monitoring and conservation are more advanced than other key pollinator groups, being increasingly used in genomic studies addressing ecological, evolutionary and conservation questions (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 taxa are retained at the species level 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 mainland Portugal (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 purposes.

FAIRness and interoperability

To ensure FAIRness and facilitate reuse in the Global Biodiversity Information Facility (GBIF) and by 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 Integrated Publishing Toolkit (IPT) guidance for checklist publication (see Wieczorek et al., 2012), and it provides both (i) a single, stable taxonomic backbone and (ii) explicit, machine-readable information on species presence and establishment status across mainland Portugal, and the Azores and Madeira Archipelagos, including individual islands.

In the Taxon core table provided in Appendix 1, we provide all the taxonomic entities described or cited in the literature for the Portuguese territory, thus representing the primary checklist table. The following identifiers and taxonomic Darwin Core backbone fields are given: scientificName (full scientific name), taxonKey (a stable internal identifier for each taxon concept, persistent across versions), the higher taxonomic classification fields kingdom, phylum, subphylum, class, order, suborder, superfamily, family, subfamily, genus, and subgenus (when applicable), as well as specificEpithet and infraspecificEpithet (when applicable), scientificNameAuthorship, taxonRank, taxonRemarks (brief taxonomic or bibliographic notes), establishmentMeans (endemic, introduced, managed, naturalised, migrant, native, uncertain, vagrant), dynamicProperties such as iucnStatus, nationalStatus, legalProtection and bernConvention, and finally, nomenclaturalCode (ICZN – International Code of Zoological Nomenclature).

In Appendix 2, we provide a distribution extension (taxon × geography statements) to encode where each taxon occurs (mainland, archipelagos, individual islands) and its establishment status, while maintaining interoperability and allowing filtering across systems. We encode geographic units in a fully machine-readable way using country (Portugal),

countryCode (PT), stateProvince (standardised reporting partitions such as Mainland, Azores and Madeira), island (individual island name when resolved to island level), and locationID with stable codes for each reporting unit (e.g., PT-ML, PT-AZ, PT-MA and island codes). The distribution by island uses the following abbreviations for the Azores: COR – Corvo; FLO – Flores; FAI – Faial; PIC – Pico; GRA – Graciosa; SJG – São Jorge; TER – Terceira; SMG – São Miguel; SMR – Santa Maria. For the Madeira and Selvagens archipelagos, the following abbreviations are used: M – Madeira; PS – Porto Santo; D – Desertas; S – Selvagens. For policy-relevant status, we maintained establishmentMeans, and included degreeOfEstablishment (captive, casual, colonising, established, failing, native, migrant, released, reproducing), and occurrenceRemarks to flag record-level uncertainty, deletions, personal communications or other special cases. The fields iucnStatus, nationalStatus, legalProtection and bernConvention are also maintained in Appendix 2. Additionally, the following fields related with distribution and detection have also been added: endemicTo, lastSeen, extinctionCause, lastMajorInflux, origin and colonizationYear. Finally, we added the field exclusionReason detailing the explanation for excluding the taxon from next steps of the analyses, followed by associatedReferences.

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 all taxa validated as present by experts into a tiered monitoring framework that reflects field feasibility, indicator value, and policy needs (Appendix 3; Table 1).

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. It also includes taxonomically challenging taxa, such as those under taxonomic revision, requiring molecular tools for identification, or difficult to distinguish reliably from closely related species, as well as taxa currently considered unsuitable as bioindicators. Tier 0 is mutually exclusive with Tiers 1-3 and represents taxa not currently recommended for monitoring.

Tier 1 (Core monitoring set) comprises common and widespread species that are reliably detected and identified in the field using standard protocols and that can provide robust indicators of community change across landscapes and over time. Because of sexual dimorphism, in some species only one sex is included in Tier 1, while the other is assigned to Tier 2. When only the female is retained in Tier 1, the species is marked with ♀; when only the male is retained in Tier 1, it is marked with ♂.

Tier 2 (Extended set) includes taxa that typically require greater taxonomic expertise, targeted sampling periods or greater sampling effort to achieve robust detection. It also includes habitat specialists and taxa expected to be particularly sensitive to restoration actions. In bees, because of the large number of species included in Tier 2 (and some in Tier 1), the highly common species are marked with *, providing a practical indication of taxa that may be less sensitive to environmental change but should nevertheless remain included in monitoring.

Tier 3 (Priority conservation set) covers threatened, range-restricted or otherwise rare taxa for which general surveillance may be insufficient. These taxa 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 field

conditions, (ii) phenological window and temporal coverage required to sample the taxon adequately, (iii) habitat association and degree of specialisation, (iv) taxonomic stability (including known species complexes and groups requiring taxonomic revision), (v) restoration sensitivity, defined as the expected response to habitat quality and management, and (vi) policy relevance, including conservation status from global, European and national IUCN Red List assessments, where available, and alignment with EU pollinator monitoring objectives. The tier system should be interpreted as an operational monitoring framework rather than as a biological ranking of species importance (Table 1). Because the three focal pollinator groups differ strongly in species richness, taxonomic complexity, detectability, ecological specialisation and conservation status, a single undifferentiated monitoring list would be difficult to implement consistently. The criteria above therefore integrate three complementary dimensions: operational feasibility, ecological and indicator relevance, and conservation priority.

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 taxonomic experts and updated through versioned checklist releases. All changes will be documented to ensure traceability and comparability while maintaining an up-to-date tool for long-term monitoring and policy implementation.

RESULTS

Diversity patterns

The Taxon core table provided in Appendix 1 includes 1,139 taxa recorded or cited for the Portuguese territory. In Appendix 2, these taxa were expanded into 1,483 taxon × geography records through the distribution extension, reflecting their occurrence across mainland Portugal, the Azores and Madeira. Following expert assessment of taxonomic and distributional validity, 1,129 taxa were retained for inclusion in the tiered monitoring framework present in Appendix 3.

Anthophila are the richest of the three focal pollinator groups in Portugal, currently comprising 746 taxa (Appendix 3) from all six 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 the 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. Regarding conservation status, one species is classified as Critically Endangered, eight as Endangered and seven as Vulnerable (Boieiro et al., 2023), all from the mainland Portugal.

Syrphids are represented by 233 species (Appendix 3), belonging to four subfamilies and 67 genera. Mainland Portugal supports the highest species diversity, with 224 species, reflecting the country's environmental heterogeneity and Iberian biogeographical context. The hoverfly fauna of the archipelagos is comparatively species-poor, with 25 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 exotic 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 (169 species). However, the checklist also features one species classified as Critically Endangered and 25 species classified as Endangered, as well as 12 Vulnerable and 19 Near Threatened species (Vujić et al., 2022; Boieiro et al., 2023). The relatively high proportion of species in threatened and Near Threatened categories (almost a third of the total) highlights their conservation relevance.

Portuguese Papilionoidea comprise 150 accepted taxa (Appendix 3), distributed across six families. Nymphalidae is the richest, with 72 taxa, followed by Lycaenidae (37), Pieridae (19), Hesperidae (18), Papilionidae (3) and Riodinidae (1). Mainland Portugal contains the highest number of accepted taxa (138), 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 11 taxa in the Azores and 20 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. Most taxa are currently classified as Least Concern (EU: 123 taxa, PT: 119 taxa). However, the checklist also features one taxon classified as Critically Endangered in Portugal, as well as Endangered (EU: 2; PT: 7), Vulnerable (EU: 4; PT: 6) and Near Threatened (EU: 17; PT: 6) taxa. In addition, two taxa are classified as Data Deficient in Portugal and one is considered Extinct in the EU (Boieiro et al., 2023; van Swaay et al., 2025). Threatened and Near Threatened taxa account for c. 16% of the checklist in the EU and c. 14% in Portugal, a lower proportion than in Syrphidae, but still of conservation concern.

519

520 **Monitoring species framework: “operational monitoring list”**

521 Building on the core species list (Appendix 1) and their spatial distribution (Appendix 2), Appendix
522 3 presents a monitoring framework that translates taxonomic knowledge into an operational tool
523 for practitioners.

524 The bee monitoring-tier dataset shows that Anthophila is the most complex group for
525 operational monitoring (Figure 2; Appendix 3). In mainland Portugal, 736 taxa were assessed, of
526 which 735 were assigned to at least one monitoring tier (Tiers 1, 2 and 3) and 1 species was
527 placed in Tier 0 (*Apis mellifera* Linnaeus, 1758), being excluded from monitoring. Only 47
528 mainland taxa were included in Tier 1, whereas 735 were included in Tier 2 and 101 in Tier 3,
529 indicating that most bee taxa require extended sampling, expert validation or targeted survey
530 conditions. In the Azores, 18 out of the 19 taxa were assigned to Tiers 1-3, with 13 Tier 1 taxa, 15
531 Tier 2 taxa and one Tier 3 taxon. In Madeira, 17 out of the 24 taxa were assigned to Tiers 1-3,
532 including 11 Tier 1 taxa, 15 Tier 2 taxa and nine Tier 3 taxa. These patterns highlight the contrast
533 between the very diverse and taxonomically demanding mainland bee fauna and the smaller
534 island faunas, where a larger proportion of species can be readily included into routine and
535 extended monitoring.

536 In mainland Portugal, all 223 syrphid taxa were assessed (Figure 2; Appendix 3), with only
537 one being placed in Tier 0, *Cheilosia* sp. aff. *fraterna*, a record based on a single female of a yet
538 unidentified species, possibly new to science, and closely related to *Cheilosia fraterna* (Meigen,
539 1830) (van Eck *et al.*, 2020). Most mainland syrphids were placed in Tier 2 (181), followed by Tier
540 1 (54) and Tier 3 (22). Over 83% (186) of the mainland species were placed in either Tier 2 or Tier

3, with 17 being assigned to both tiers. This pattern highlights the need for specific sampling protocols on targeted sampling sites, as well as expert verification of species identifications, when dealing with mainland hoverflies. Regarding the Azores and Madeira, both showed similar patterns, with most species placed in Tier 1 (22 and 23, respectively), followed by Tier 2 (9 and 13, respectively) and Tier 3 (3 and 4, respectively). Additionally, a relatively large proportion of hoverfly species were placed in Tiers 1, 2 and 3 simultaneously (3 and 4, for the Azores and Madeira, respectively), corresponding to endemic species, which are generally easy to identify, habitat specialists and, in most cases, threatened. The high number of species from the Azores and Madeira placed in Tier 1 highlights the contrast between mainland Portugal and the Macaronesian archipelagos: in mainland Portugal, due to its relatively higher species diversity, many species might require greater monitoring effort, while on the islands, which are smaller and relatively less biodiverse, species identification and monitoring may be accomplished more easily.

The butterfly monitoring-tier framework reflects the comparatively mature taxonomic knowledge and well-established monitoring methods available for this group (Figure 2; Appendix 3). In mainland Portugal, 83 taxa were assigned to Tier 1, 77 to Tier 2 and 25 to Tier 3, while 9 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 25 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.

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 richness patterns relevant for conservation 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 1,129 taxa among the three focal pollinator groups (Appendix 3) 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 priorities.

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 (see Figure 2). This does not diminish their value for monitoring; rather, it shows that their inclusion must be

606 matched by realistic investment in taxonomic capacity, reference collections and quality-control
607 procedures.

608 Similarly to bees, although harbouring substantially fewer species, mainland hoverflies
609 still represent a substantial operational challenge for monitoring. The large number of taxa
610 assigned to Tier 2 indicates that many species also require increased sampling effort, specialist
611 identification or targeted survey conditions, while those assigned to Tier 3 additionally require
612 targeted conservation monitoring. In contrast, a larger proportion of the Azorean and Madeiran
613 hoverfly faunas can be incorporated into routine monitoring because of the lower species
614 richness in these regions, although several endemic species also fall within the extended and
615 priority tiers. These patterns highlight the need to combine standardised monitoring with
616 sufficient taxonomic expertise and targeted approaches, particularly for mainland taxa and island
617 endemics.

618 In contrast, a comparatively high proportion of butterflies can be incorporated into
619 routine monitoring, reflecting their more stable taxonomy, established field methods, greater
620 availability of identification resources and the relative ease with which these tools can be applied
621 in practice. However, even in this comparatively well-known group, habitat specialists, taxa with
622 restricted phenological windows and conservation-priority species still require extended or
623 targeted approaches to minimise well-known biases that directly affect conservation efforts
624 (Dapporto et al., 2026).

625 The mainland and archipelagic faunas also require different monitoring priorities. Whilst
626 mainland Portugal combines high richness with strong environmental heterogeneity and
627 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. However, 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. These characteristics may require monitoring approaches that go beyond routine community-level surveillance. Routine 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 clear and operationally relevant. Periodic revision will be essential as taxonomic knowledge, distributional data and identification capacity continue to improve.

From monitoring tiers to PT-PoMS implementation

The EU Nature Restoration Regulation creates a direct policy requirement for robust and repeatable data on pollinator abundance and species richness. Article 10 of Regulation (EU) 2024/1991 demands Member States to reverse pollinator decline, while the Commission

Delegated Regulation (EU) 2025/2188 based on the European Pollinator Monitoring Scheme, establishes a scientifically grounded methodology for a harmonised implementation (European Union, 2024; Potts et al., 2021, 2024). Additionally, the proposed Portuguese Pollinator Monitoring Scheme (PT-PoMS) offers the national setting in which the checklist and monitoring tiers can be translated into practice (Ministry of Environment and Energy, 2026). 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. A recently approved LIFE project for the Pollinators of Azores (LIFE24-NAT-PT-LIFE POLINIZACORES) will test this species list. 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 should be regarded as a provisional operational category: it represents taxa that are not currently recommended for monitoring but may be reassigned to Tiers 1-3 as taxonomic knowledge, identification tools and sampling methods improve.

The implementation of PT-PoMS should follow the monitoring requirements established by Commission Delegated Regulation (EU) 2025/2188, which defines the sampling design, temporal coverage, data collection protocols and identification requirements to be applied by Member States. Accordingly, the national scheme should be spatially representative and

repeatable over time, using a stratified random sampling design based on the LUCAS grid (European Union, 2024; 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 the representativeness of the monitoring network. Temporal coverage must also reflect regional phenology. The monitoring periods established for Portugal (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 (ICNF, personal communication).

Given the differences in detectability, phenology, habitat use and taxonomic difficulty among bees, hoverflies and butterflies, complementary monitoring methods will be necessary (Potts et al., 2021, 2024). 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 (Potts et al., 2024). Complementary modules, including random transects with flight interception sampling and passive flight-interception methods such as Malaise traps, can provide rapid and broad assessments of pollinator diversity, strengthening the information obtained from regular transects and facilitating molecular identification approaches that reduce dependence on taxonomic identification capacity (Settele et al., 2024). Citizen-led monitoring can increase geographic coverage and public engagement, but it should complement rather than replace the statistically designed core network (Justine & Balakrishnan, 2026). Its contribution will depend on clear protocols, appropriate training, data curation and expert verification where required (Garraat et al., 2019; Justine & Balakrishnan, 2026).

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. Over time, sustained investment in taxonomic capacity and research is expected to allow reassignment of taxa among monitoring tiers, particularly for bees and hoverflies, as knowledge, identification tools and monitoring experience improve (Figure 3). Strengthening taxonomic capacity will, in turn, improve our ability to detect population declines, disentangle cryptic diversity, and identify species-specific habitat requirements for these functionally important taxa.

FAIR data infrastructure and long-term governance

The checklist should form the taxonomic component of a broader FAIR data 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 allow the present appendices to evolve from static supporting files into maintained and citable resources, enabling 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 the combination 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 (Sevilleja et al., 2020; van Swaay et al., 2008; 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 regarded as interconnected components of a long-term monitoring system.

Limitations, priorities and policy relevance

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. Additionally, 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).

The framework presented here links taxonomic knowledge, territorial distribution, monitoring feasibility and conservation priority to 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.

AUTHOR CONTRIBUTIONS

Conceptualisation: Paulo A. V. Borges and Sílvia Castro. **Funding acquisition:** Sílvia Castro, Hugo Gaspar and João Loureiro. **Taxonomic investigation, data curation and validation:** Eduardo Marabuto, Francisco Gil and Hugo Gaspar, with contributions from all authors according to their respective areas of expertise. **Methodology:** all authors, particularly through the collaborative development of the monitoring-tier framework. **Writing – original draft:** Paulo A. V. Borges, with key contributions from Eduardo Marabuto, Francisco Gil, Hugo Gaspar and Sílvia Castro. **Writing – review and editing:** all authors, each of whom participated in at least three rounds of manuscript revision. **Data analysis:** Tatiana Moreira, with key contributions of Eduardo Marabuto, Francisco Gil and Hugo Gaspar. **Supervision and project administration:** Sílvia Castro and Paulo A. V. Borges. All authors read and approved the final manuscript.

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815 **CONFLICT OF INTEREST STATEMENT**

816 The authors confirm that they had no conflict of interest in this study.

817

818 **SUPPORTING INFORMATION**

819 Additional supporting information can be found online in the Supporting Information section at
820 the end of this article.

821

822 **DATA AVAILABILITY STATEMENT**

823 The data are available at: <https://islandlab.uac.pt/software/ver.php?id=129>

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TABLES

TABLE 1. Description of Tiers combinations used in Appendix 3. Tier 0 is an exclusion category and is therefore not combined with Tiers 1-3. Note: Counts refer to territory-level taxon records; therefore, 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

FIGURE CAPTIONS

FIGURE 1. (a) Location of the study area, showing the three territorial units considered in the study. (b) Mainland Portugal, with district boundaries. (c) Azores archipelago. (d) Madeira archipelago, including Selvagens Islands.

FIGURE 2. Taxonomic and geographical allocation of Portuguese pollinators across operational monitoring tiers. Chord diagrams depicting the relationships between focal pollinator groups (bees, hoverflies, and butterflies) and proposed monitoring tiers (Tier 0 to Tier 3) across Madeira, the Azores, and mainland Portugal. Group contribution per tier, showing the taxonomic composition that constitutes each monitoring category within each geographical unit. Ribbons represent the allocation of species between taxonomic groups and monitoring tiers, with ribbon widths and outer numbers indicating absolute species counts in each category (n). Operational tiers reflect monitoring feasibility and requirements (see methodology) Tier 0 (not considered to monitoring efforts), Tier 1 (standardised community surveillance), Tier 2 (extended effort needing specialist identification), and Tier 3 (rare, with restricted distributions and/or with threatened taxa requiring targeted conservation protocols).

FIGURE 3. Conceptual framework for the temporal progression of monitoring tiers within the Portuguese Pollinator Monitoring Scheme (PT-PoMS). At baseline (Year 0 – left half), knowledge gaps define a provisional T0 category, while taxa are assigned to Core (T1), Specialist (T2) and Priority (T3) tiers. During the transition phase, capacity building and targeted research validate and refine these assignments, progressively reducing uncertainty. Long-term re-evaluations (Year

1061 20 – right half), sustained policy commitment and taxonomic development are expected to
1062 enhance our ability to monitor population trends, uncover cryptic diversity and characterize
1063 habitat requirements, while ultimately recalibrating tier distributions and channelling resources
1064 towards functionally important and vulnerable taxa.

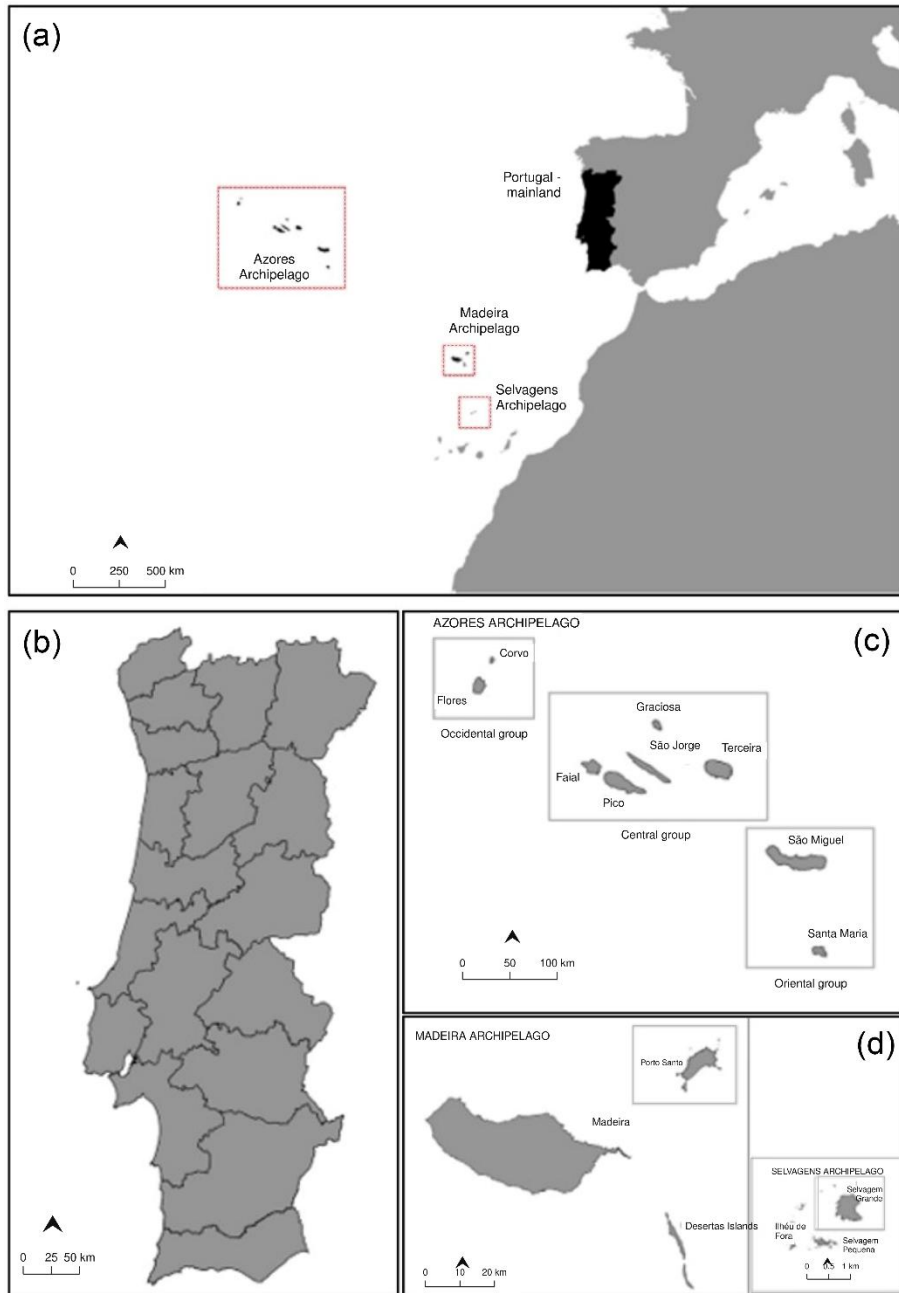
SUPPORTING INFORMATION

APPENDIX 1. Taxon core checklist of bees (Anthophila), hoverflies (Syrphidae) and butterflies (Papilionoidea) recorded or cited for the Portuguese territory, including mainland Portugal, the Azores and Madeira. This table represents the primary taxonomic checklist of the dataset and provides Darwin Core-compatible information on taxonomic classification, nomenclature, establishment status, conservation status and taxonomic or bibliographic remarks.

APPENDIX 2. Distribution extension associated with the Taxon core checklist provided in Appendix 1, containing taxon-by-geography records for bees (Anthophila), hoverflies (Syrphidae) and butterflies (Papilionoidea) across mainland Portugal, the Azores and Madeira, including individual islands where information is available. The table provides Darwin Core-compatible information on geographic occurrence, establishment and conservation status, complemented by fields describing endemism, temporal occurrence, colonisation, origin, record uncertainty, exclusion decisions and the associated bibliographic evidence.

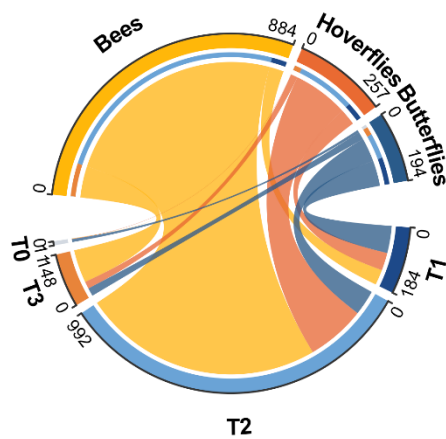
APPENDIX 3. Operational monitoring framework derived from the taxonomic and distributional information provided in Appendices 1 and 2, including bees (Anthophila), hoverflies (Syrphidae) and butterflies (Papilionoidea) considered present in mainland Portugal, the Azores and Madeira following expert review. Taxa are assigned to one or more monitoring tiers according to operational feasibility, ecological and indicator relevance, and conservation priority. Tier 0 is an exclusion category for taxa not currently recommended for monitoring and cannot be combined

1086 with Tiers 1-3. Tier 1 represents the Core monitoring set, Tier 2 the Extended monitoring set and
1087 Tier 3 the Priority conservation set.

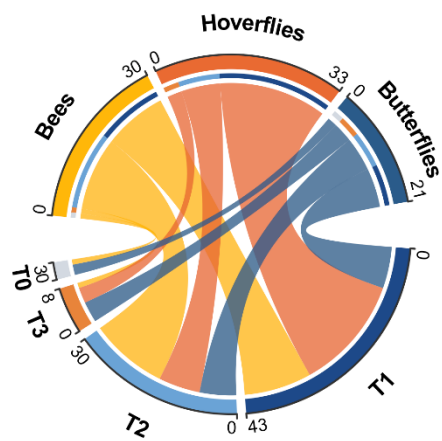


1088 **FIGURE 1**

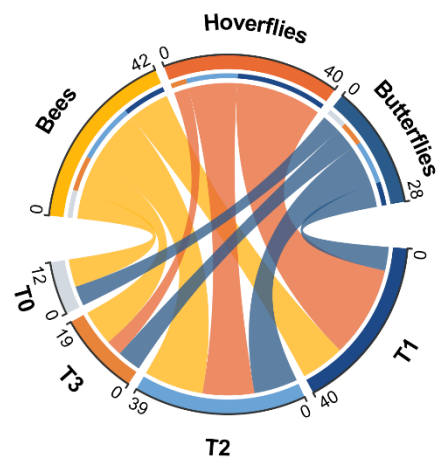
Mainland



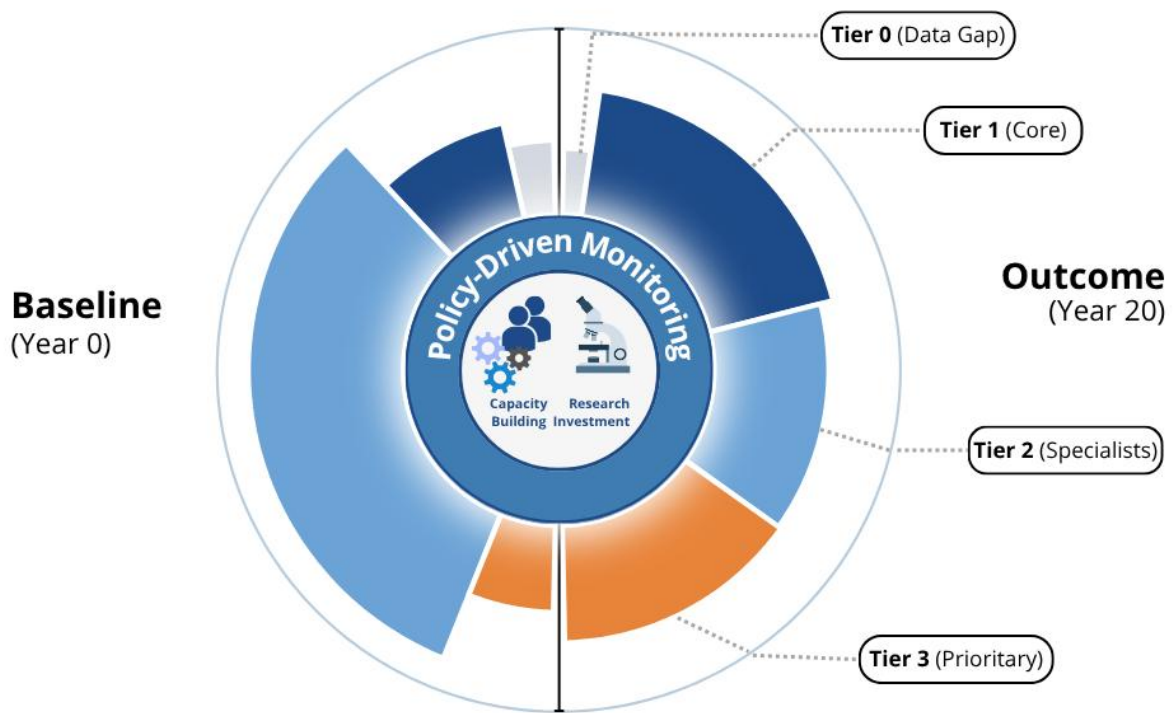
Azores



Madeira



1089 **FIGURE 2**



1090 **FIGURE 3**