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SLAM Project - Long Term Ecological Study of the Impacts of Climate Change in the natural forest of Azores : IV - The spiders of Terceira and Pico Islands (2019-2021) and general diversity patterns after ten years of sampling

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# SLAM Project - Long Term Ecological Study of the Impacts of Climate Change in the natural forest of Azores: IV - The spiders of Terceira and Pico Islands (2019-2021) and general diversity patterns after ten years of sampling

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## Abstract

### Background

Long-term studies are key to understand the drivers of biodiversity erosion, such as land-use change and habitat degradation, climate change, invasive species or pollution. The long-term project SLAM (Long Term Ecological Study of the Impacts of Climate Change in the natural forest of Azores) started in 2012 and focuses on arthropod monitoring, using SLAM (Sea, Land and Air Malaise) traps, aiming to understand the impact of the drivers of biodiversity erosion on Azorean native forests (Azores, Portugal). This is the fourth contribution including SLAM project data and the second focused on the spider fauna (Arachnida, Araneae) of native forests on two islands (Pico and Terceira). In this contribution, we describe data collected between 2019 and 2021 and we analyse them together with a previously published database that covered the 2012-2019 period, in order to describe changes in species abundance patterns over the last ten years.

### New information

We present abundance data of Azorean spider species for the 2019-2021 period in two Azorean Islands (Terceira and Pico). We also present analyses of species distribution and abundance of the whole sampling period. In the period of 2019-2021, we collected a total of 5110 spider specimens, of which 2449 (48%) were adults. Most juveniles, with the exception of some exotic Erigoninae, were also included in the data presented in this paper, since the low diversity of spiders in the Azores allows a relatively precise species-level identification of this life-stage. We recorded a total of 45 species, belonging to 39 genera and 16 families. The ten most abundant species were composed mostly of endemic or native non-endemic species and only two exotic species (*Tenuiphantes tenuis* (Blackwall, 1852) and *Dysdera crocata* C. L. Koch, 1838). They included 4308 individuals (84%) of all sampled specimens and were the dominant species in Azorean native forests. The family Linyphiidae was the richest and most abundant *taxon*, with 15 (33%) species and 2630 (51%) specimens. We report *Cheiracanthium mildei* L. Koch, 1864, a non-native species, from Pico Island for the first time. We found no new species records on Terceira Island. This publication contributes to increasing the baseline information for future long-term comparisons of the spiders on the studied sites and the knowledge of the arachnofauna of the native forests of Terceira and Pico, in terms of species abundance, distribution and diversity across seasons for a 10 years period.

### Keywords

Arthropoda, Araneae, long-term sampling, Azores, Macaronesia, native forest, SLAM trap

## Introduction

Humanity is facing a biodiversity crisis (Caujapé-Castells et al. 2010, Hanski 2011, Heleno et al. 2020, Fernández-Palacios et al. 2021) due to recent expansion and intensification of human disturbance, which is particularly visible on island systems (Baret et al. 2006, Gaspar et al. 2008, Borges et al. 2019, Borges et al. 2020). The spread of exotic species is one of the major concerns, as biotic invasions are recognised as one of the main causes of species extinction (Pyšek et al. 2020). Scientists have pointed out the critical importance to consider long-term monitoring schemes to track species' response to introductions for a better assessment of extinction risk. However, long-term baseline studies are the exception rather than the rule in literature, especially for less conspicuous taxa, such as arthropods (Henriques et al. 2017, Borges et al. 2018, Costa and Borges 2021, Vancutsem et al. 2021). Although long-term monitoring may be expensive and/or hard to implement (Caughlan and Oakley 2001), the resulting data allow the recording of changes in biodiversity composition and abundance, which allow for better estimates of the trends and more accurate predictions of future of communities through the so-called time series analyses (Loh et al. 2005, Dornelas et al. 2013, Coops et al. 2014, Dornelas et al. 2014) and is, thus, well worth the effort.

Spiders are one of the most well-known groups of arthropods in the Azores Archipelago due to a number of past studies (see, for example, Borges and Wunderlich 2008, Cardoso et al. 2010, Borges et al. 2013, Malumbres-Olarte et al. 2019, Carvalho et al. 2021) and they are one of the most useful to assess biodiversity change (New 1999). Nevertheless, we still lack suitable population and demographic information, which limits proper assessment of the conservation status of many species and of the colonisation dynamics of alien species that threaten the ecosystem (Borges et al. 2020).

Since 2012, we have sampled the arthropod communities in the remaining native forests fragments of the Azores Archipelago through the SLAM project (Long Term Ecological Study of the Impacts of Climate Change in the natural forest of Azores), using a large number of SLAM traps across several islands (Borges et al. 2017, Matthews et al. 2018, Costa and Borges 2021, de Vries et al. 2021, Tsafack et al. 2021, Borges et al. 2022a, Borges et al. 2022b).

## General description

**Purpose:** This publication is the fourth data-paper contribution to the long-term project SLAM (Long Term Ecological Study of the Impacts of Climate Change in the natural forest of Azores) that started in 2012 with the aim of understanding the impact of the drivers of biodiversity erosion on Azorean native forests (Azores, Portugal) (see Costa and Borges 2021, Borges et al. 2022a, Borges et al. 2022b). This publication is also the second of the series that explores time-series data for the spider fauna in Pico and Terceira Islands (Azores Archipelago) (see the first contribution in Costa and Borges 2021).

We used passive flight interception SLAM traps (Sea, Land and Air Malaise trap) (MegaView Science Co. Ltd., Taichung City, Taiwan) (Fig. 1) to sample native forest plots in several Azorean islands, with one trap placed at each plot. This publication aims to document the most recent data (from winter 2020 to autumn 2021 on Terceira and from winter 2019 to Autumn 2021 on Pico) as an extension of the previous database published by Costa and Borges (2021) following the same sampling strategy. Besides, we also incorporate a recent taxonomic change over the database, where *Sancus acoreensis* (Wunderlich, 1992) becomes *Leucognatha acoreensis* Wunderlich, 1992 (Ceccolini and Cianferoni 2022).



Figure 1. [doi](#)

SLAM - Sea, Land and Air Malaise trap. Credit: Paulo A. V. Borges.

**Additional information:** The year 2012 marks the beginning of the survey of arthropods in Terceira Island through SLAM traps, within the Project NETBIOME ISLANDBIODIV. In Pico Island, the study started in September 2013. Since 2020, the SLAM project has been financed within the project LIFE-BEETLES. Samples were collected by the University of the Azores team members in Terceira Island and by Pico Nature Park rangers in Pico Island.

The statistical analyses presented and commented in the Discussion are based on the complete dataset on spiders from 2012-2021, including all samples since the beginning of the study, using also the data published by Costa and Borges (2021). In a few cases, it was impossible to collect the SLAM traps on some sites and seasons (22 EventID out of

665 recorded) and sampling periods extended over three months. In order to be consistent, we removed sampling events that are related to more than one season.

## Project description

**Title:** SLAM - Long Term Ecological Study of the Impacts of Climate Change in the natural forest of Azores

**Personnel:** Paulo A.V. Borges conceived and coordinated the project.

**Fieldwork:** For the period 2019-2021 (Terceira Island) - Paulo A. V. Borges, Rui Carvalho, Rui Nunes, Sébastien Lhoumeau; (Pico Island) - Paulo Freitas, Sónia Manso.

**Parataxonomists:** For the period 2019-2021 – Abrão Leite, Adrian Fernandez Martinez, Emanuela Cosma, Jonne Bonnet, Joel Martin Aye, Loïc Navarro, Magí Ramon Martorell, Marco Canino, Natalia Fierro Frerot, Sébastien Lhoumeau, Valentin Moley.

**Taxonomists:** Paulo A. V. Borges and Luís Carlos Crespo

**Curation:** Voucher specimen management was mainly undertaken by Abrão Leite, Sébastien Lhoumeau and Paulo A. V. Borges.

**Study area description:** The Azores are an isolated archipelago ( $38^{\circ}43'49''\text{N}$ ,  $27^{\circ}19'10''\text{W}$ , Fig. 2), situated in the mid-Atlantic Ocean comprising nine volcanic Islands spread over 500 km in a W/NW–E/SE direction. During this project, eight Islands (Corvo, Flores, Faial, Pico, Graciosa, Terceira, S. Miguel and S. Maria) were surveyed within the SLAM Project. However, only Pico (Fig. 3) and Terceira Islands (Fig. 4) were continuously monitored since 2012 and 2013, respectively and are, thus, selected for this work.

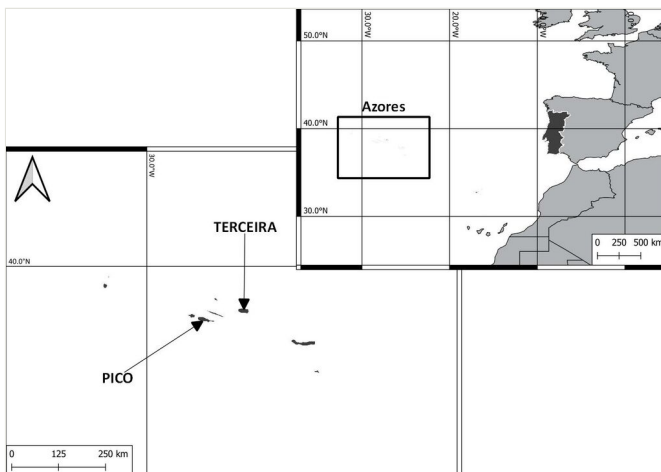


Figure 2. [doi](#)

Location of the Azores Archipelago and the Islands of Pico and Terceira.

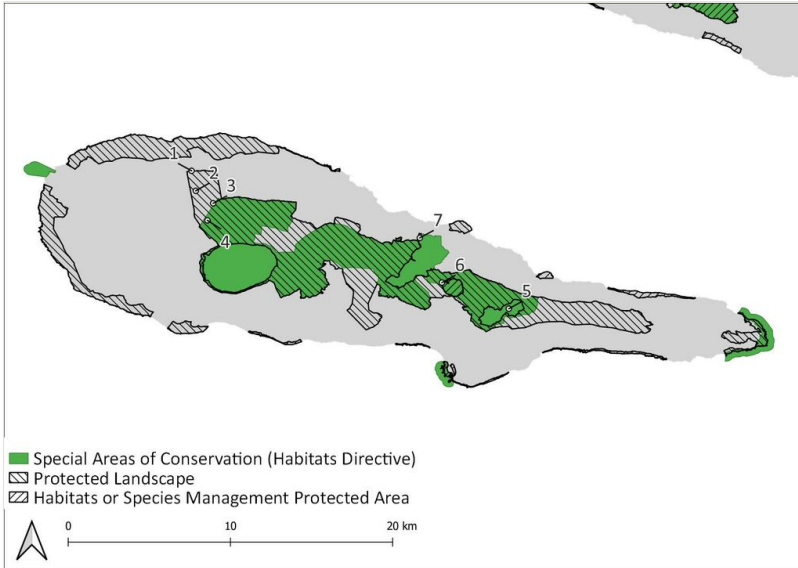


Figure 3. [doi](#)

Location of sampling sites on Pico Island 1: PIC\_ML\_200; 2: PIC\_ML\_400; 3: PIC\_ML\_600; 4: PIC\_ML\_800; 5: PIC-NFCA-T-09; 6: PIC-NFLC-T-02; 7: PIC-NFMP-T-03.

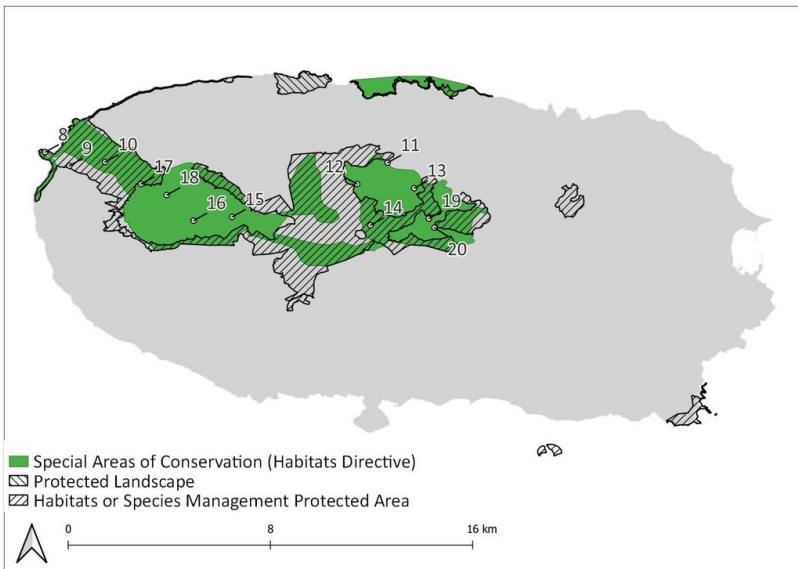


Figure 4. [doi](#)

Location of sampling sites on Terceira Island. 8: TER\_0M; 9: TER\_200M; 10: TER\_400M; 11: TER-NFBF-T-01; 12: TER-NFBF-T-02; 13: TER-NFBF-TP41; 14: TER-NFPG-T-33; 15: TER-NFSB-T-07; 16: TER-NFSB-T164; 17: TER-NFSB-TE48; 18: TER-NFSB-TE49; 19: TER-NFTB-T-15; 20: TER-NFTB-T-18\_Original.

**Design description:** We sampled in the Azorean Islands of Terceira and Pico, four times per year (mid-March (winter sample), mid-June (spring sample), mid-September (summer sample) and mid-December (autumn sample)).

**Funding:** The following sources of funding were available during the 2019-2021 period:

- FEDER - AZORESBIOPORTAL –PORBIOTA (ACORES-01-0145-FEDER-000072)
- EU ERASMUS + Training Grants to Adrian Fernandez Marinez, Emanuela Cosma, Jonne Bonnet, Joel Martin Aye, Loïc Navarro, Magí Ramon Martorell, Marco Canino, Natalia Fierro Frerot, Sébastien Lhoumeau and Valentin Moley.
- Direcção Regional do Ambiente – LIFE-BETTLES (LIFE18 NAT\_PT\_000864).
- Science and Technology Foundation (FCT) - MACRISK-Trait-based prediction of extinction risk and invasiveness for Northern Macaronesian arthropods (FCT-PTDC/BIA-CBI/0625/2021).
- Portal da Biodiversidade dos Açores (2022-2023) - PO Azores Project - M1.1.A/INFRAEST CIENT/001/2022.

## Sampling methods

**Description:** Overall, we sampled a total of twenty plots, thirteen on Terceira Island and seven on Pico Island, using SLAM traps (Table 1) (see Costa and Borges 2021). The plots are located in some of the best preserved native forest patches of the two Islands, having only limited human disturbance (Borges et al. 2017).

Table 1.

The list of the twenty sampled sites in the Islands of Pico (n = 7) and Terceira (n = 13).

| Island | Location ID   | Site name    | Municipality      | Fragment name         | Habitat       | Latitude | Longitude | Elevation (m) |
|--------|---------------|--------------|-------------------|-----------------------|---------------|----------|-----------|---------------|
| Pico   | PIC-ML-200    | Plot 200m    | Madalena          | Mistério de St. Luzia | Mixed Forest  | 38.5348  | -28.4341  | 199           |
| Pico   | PIC-ML-400    | Plot 400m    | Madalena          | Mistério de St. Luzia | Mixed Forest  | 38.5207  | -28.4311  | 428           |
| Pico   | PIC-ML-600    | Plot 600m    | São Roque do Pico | Mistério de St. Luzia | Mixed Forest  | 38.5119  | -28.4189  | 627           |
| Pico   | PIC-ML-800    | Plot 800m    | São Roque do Pico | Mistério de St. Luzia | Mixed Forest  | 38.4999  | -28.4229  | 797           |
| Pico   | PIC-NFCA-T-09 | Caveiro Base | Lajes do Pico     | Pico Caveiro          | Native Forest | 38.4377  | -28.2106  | 937           |
| Pico   | PIC-NFLC-T-02 | Euphorbias   | Lajes do Pico     | Lagoa do Caiado       | Native Forest | 38.4561  | -28.2577  | 804           |



| Island   | Location ID            | Site name                  | Municipality      | Fragment name          | Habitat             | Latitude | Longitude | Elevation (m) |
|----------|------------------------|----------------------------|-------------------|------------------------|---------------------|----------|-----------|---------------|
| Pico     | PIC-NFMP-T-03          | Chão Verde inferior        | São Roque do Pico | Mistério da Prainha    | Native Forest       | 38.4876  | -28.2733  | 475           |
| Terceira | TER-0M                 | Farol da Serreta           | Angra do Heroísmo | Farol da Serreta       | <i>Erica</i> Forest | 38.7666  | -27.3748  | 46            |
| Terceira | TER-200M               | Serreta 200m               | Angra do Heroísmo | Mata da Serreta        | Mixed Forest        | 38.7604  | -27.3638  | 237           |
| Terceira | TER-400M               | Mirador do Pico Carneiro   | Angra do Heroísmo | Mata da Serreta        | Mixed Forest        | 38.7621  | -27.3476  | 397           |
| Terceira | TER-NFBF-T-01          | Labaçal - Morro Assombrado | Praia da Vitória  | Biscoito da Ferraria   | Native Forest       | 38.7618  | -27.2193  | 678           |
| Terceira | TER-NFBF-T-02          | Chambre A                  | Praia da Vitória  | Biscoito da Ferraria   | Native Forest       | 38.7521  | -27.2331  | 590           |
| Terceira | TER-NFBF-TP41          | Pico Alto Nascente         | Praia da Vitória  | Biscoito da Ferraria   | Native Forest       | 38.7502  | -27.2072  | 673           |
| Terceira | TER-NFPG-T-33          | Pico X B                   | Praia da Vitória  | Pico Galhardo          | Native Forest       | 38.7334  | -27.2271  | 642           |
| Terceira | TER-NFSB-T-07          | Lomba                      | Angra do Heroísmo | Serra de Santa Bárbara | Native Forest       | 38.7372  | -27.2899  | 683           |
| Terceira | TER-NFSB-T164          | Caldeira - Silvia          | Angra do Heroísmo | Serra de Santa Bárbara | Native Forest       | 38.7355  | -27.3074  | 900           |
| Terceira | TER-NFSB-TE48          | Lagoinha B                 | Angra do Heroísmo | Serra de Santa Bárbara | Native Forest       | 38.7521  | -27.3313  | 687           |
| Terceira | TER-NFSB-TE49          | Lagoa Pinheiro B           | Angra do Heroísmo | Serra de Santa Bárbara | Native Forest       | 38.7471  | -27.3196  | 918           |
| Terceira | TER-NFTB-T-15          | Terra Brava - A            | Praia da Vitória  | Terra Brava            | Native Forest       | 38.7364  | -27.2006  | 637           |
| Terceira | TER-NFTB-T-18_ORIGINAL | Terra Brava - B -Original  | Praia da Vitória  | Terra Brava            | Native Forest       | 38.7323  | -27.1980  | 686           |

The sampling plots are mostly dominated by endemic vegetation like *Juniperus brevifolia*, *Erica azorica*, *Laurus azorica* and *Ilex azorica* (see Borges et al. 2017 for more details). In Pico Island, the plots located at lower elevations (0-400 m a.s.l.) are dominated by *Erica azorica* and *Morella faya*, but with some presence of the invasive species, *Pittosporum undulatum*. At higher elevations (600-1000 m a.s.l.), the dominant vegetation is similar to that found in Terceira Island' plots.

**Sampling description:** In the laboratory, specimen sorting and spider identification followed standard procedures, using morphologic and copulatory features for species

identification. A reference collection was made for all collected specimens (whether or not identified at species level) by assigning them a morphospecies code and depositing them at the Dalberto Teixeira Pombo Insect Collection (DTP), University of Azores (Terceira Island).

Spider juvenile identification is very important in spider studies (Domènech et al. 2022). Most juveniles, with the exception of some exotic Erigoninae, were also included in the data presented in this paper, since the low diversity of spiders in the Azores allows a relatively precise species-level identification of this life-stage.

## Geographic coverage

**Description:** Pico and Terceira Islands, the Azores, Macaronesia, Portugal (Fig. 2)

**Coordinates:** 38.835 and 38.372 Latitude; -28.592 and -26.993 Longitude.

## Taxonomic coverage

**Description:** Araneae (Arthropoda, Arachnida)

## Traits coverage

Functional trait data including detailed morphometric measurements for most of the studied species can be accessed in the publication by Macías-Hernández et al. (2020).

## Temporal coverage

**Notes:** 11 December 2019 to 12 March 2022 for Terceira Island and 17 December 2018 to 7 January 2022 for Pico Island.

## Collection data

**Collection name:** Dalberto Teixeira Pombo insect collection at the University of Azores.

**Collection identifier:** DTP

**Specimen preservation method:** All specimens were preserved in 96% ethanol.

**Curatorial unit:** Dalberto Teixeira Pombo insect collection at the University of the Azores (Curator: Paulo A. V. Borges).

## Usage licence

Usage licence: Creative Commons Public Domain Waiver (CC-Zero)

## Data resources

Data package title: Long-term monitoring of Azorean Forest Spiders - Part 2

Resource link: [http://ipt.gbif.pt/ipt/resource?r=spiders\\_azores\\_2021](http://ipt.gbif.pt/ipt/resource?r=spiders_azores_2021)

Alternative identifiers: <https://www.gbif.org/dataset/f8b3ed49-f65d-4989-add0-9a726b1e745a>

Number of data sets: 2

Data set name: Event Table

Character set: UTF-8

Download URL: [http://ipt.gbif.pt/ipt/resource?r=spiders\\_azores\\_2021](http://ipt.gbif.pt/ipt/resource?r=spiders_azores_2021)

Data format: Darwin Core Archive format

Data format version: Version 1.3

**Description:** The dataset was published in the Global Biodiversity Information Facility platform, GBIF (Lhoumeau and Borges 2022). The following data table includes all the records for which a taxonomic identification of the species was possible. The dataset submitted to GBIF is structured as a sample event dataset that has been published as a Darwin Core Archive (DwCA), which is a standardised format for sharing biodiversity data as a set of one or more data tables. The core data file contains 155 records (eventID). This GBIF IPT (Integrated Publishing Toolkit, Version 2.6.2) archives the data and, thus, serves as the data repository. The data and resource metadata are available for download in the Portuguese GBIF Portal IPT (Lhoumeau and Borges 2022).

| Column label     | Column description                                  |
|------------------|---|
| id               | Unique identification code for sampling event data. |
| eventID          | Identifier of the events, unique for the dataset.   |
| samplingProtocol | The sampling protocol used to capture the species.  |
| sampleSizeValue  | The numeric amount of time spent in each sampling.  |
| sampleSizeUnit   | The unit of the sample size value.                  |
| eventDate        | Date or date range the record was collected.        |
| eventRemarks     | Information about the season and year of the event. |

|                               |  |
|-------------------------------|--|
| habitat                       | The habitat from which the sample was obtained.  |
| locationID                    | Identifier of the location.  |
| islandGroup                   | Name of archipelago.   |
| island                        | Name of the island.  |
| country                       | Country of the sampling site.  |
| countryCode                   | ISO code of the country of the sampling site.  |
| stateProvince                 | Name of the region of the sampling site.   |
| municipality                  | Municipality of the sampling site.   |
| locality                      | Name of the locality.  |
| minimumElevationInMetres      | The lower limit of the range of elevation (altitude, usually above sea level), in metres.  |
| locationRemarks               | Details on the locality site.  |
| decimalLatitude               | Approximate centre point decimal latitude of the field site in GPS coordinates.  |
| decimalLongitude              | Approximate centre point decimal longitude of the field site in GPS coordinates.   |
| geodeticDatum                 | The ellipsoid, geodetic datum or spatial reference system (SRS) upon which the geographic coordinates given in decimalLatitude and decimalLongitude are based.                                       |
| coordinateUncertaintyInMetres | Uncertainty of the coordinates of the centre of the sampling plot, in metres.  |
| coordinatePrecision           | Precision of the coordinates.  |
| georeferenceSources           | A list (concatenated and separated) of maps, gazetteers or other resources used to georeference the Location, described specifically enough to allow anyone in the future to use the same resources. |

**Data set name:** Occurrence Table

**Character set:** UTF-8

**Download URL:** [http://ipt.gbif.pt/ipt/resource?r=spiders\\_azores\\_2021](http://ipt.gbif.pt/ipt/resource?r=spiders_azores_2021)

**Data format:** Darwin Core Archive format

**Data format version:** Version 1.3

**Description:** The dataset was published in the Global Biodiversity Information Facility platform, GBIF (Lhoumeau and Borges 2022). The following data table includes all the records for which a taxonomic identification of the species was possible. The dataset submitted to GBIF is structured as an occurrence table that has been published as a Darwin Core Archive (DwCA), which is a standardised format for sharing biodiversity data as a set of one or more data tables. The core data file contains 978 records (occurrenceID). This GBIF IPT (Integrated Publishing Toolkit, Version 2.6.2) archives

the data and, thus, serves as the data repository. The data and resource metadata are available for download on the Portuguese GBIF Portal IPT (Lhoumeau and Borges 2022).

| Column label         | Column description  |
|----------------------|---|
| id                   | Unique identification code for species abundance data. Equivalent here to eventID.  |
| type                 | Type of the record, as defined by the Public Core standard.   |
| licence              | Reference to the licence under which the record is published.   |
| institutionID        | The identity of the institution publishing the data.  |
| collectionID         | The identity of the collection publishing the data.   |
| institutionCode      | The code of the institution publishing the data.  |
| collectionCode       | The code of the collection where the specimens are conserved.   |
| datasetName          | Name of the dataset.  |
| basisOfRecord        | The nature of the data record.  |
| recordedBy           | A list (concatenated and separated) of names of people, groups or organisations who performed the sampling in the field.                  |
| occurrenceID         | Identifier of the record, coded as a global unique identifier.  |
| organismQuantity     | A number or enumeration value for the quantity of organisms.  |
| organismQuantityType | The type of quantification system used for the quantity of organisms.   |
| sex                  | The sex and quantity of the individuals captured.   |
| lifeStage            | The life stage of the organisms captured.   |
| establishmentMeans   | The process of establishment of the species in the location, using a controlled vocabulary: 'native', 'introduced', 'endemic', "unknown". |
| eventID              | Identifier of the events, unique for the dataset.   |
| identifiedBy         | A list (concatenated and separated) of names of people, groups or organisations who assigned the Taxon to the subject.                    |
| dateIdentified       | The date on which the subject was determined as representing the Taxon.   |
| scientificName       | Complete scientific name including author and year.   |
| kingdom              | Kingdom name.   |
| phylum               | Phylum name.  |
| class                | Class name.   |
| order                | Order name.   |
| family               | Family name.  |
| genus                | Genus name.   |

|                          |  |
|--------------------------|--|
| specificEpithet          | Specific epithet   |
| taxonRank                | Lowest taxonomic rank of the record.   |
| scientificNameAuthorship | Name of the author of the lowest taxon rank included in the record.                          |
| identificationRemarks    | Information about morphospecies identification (code in Dalberto Teixeira Pombo Collection). |

## Additional information

### Results

During the 2019-2021 period, we collected a total of 5110 specimens [2449 (51%) adults], belonging to 45 species of spiders, 39 genera and 16 families. A total of fourteen species were endemic to the Azores Archipelago (2416 specimens; 1114 adults), nine species were native non-endemic (1793 specimens; 1006 adults) and twenty-two species were introduced (901 specimens, 329 adults) (Table 2).

Table 2.

List of the recorded species between 2019 and 2021 with their corresponding family, colonisation status (E - endemic from Azores; N - native non-endemic; I - exotic introduced species), IUCN status for the endemic species (in parenthesis together with the colonisation status; VU - Vulnerable; NT - Near Threatened; LC - Least Concern) and overall abundance (adults + juveniles) in each of the two studied Islands and total abundance of specimens. The new records are marked with a (\*). The ten most abundant species are in bold.

| Family           | Species  | Colonis. | Pico  | Terceira | Total Abundance |
|------------------|--|----------|-------|----------|-----------------|
| Agelenidae       | <i>Tegenaria domestica</i> (Clerck, 1757)              | I        | 2     | 0        | 2               |
| Agelenidae       | <i>Textrix caudata</i> L. Koch, 1872                   | I        | 0     | 5        | 5               |
| Araneidae        | <b><i>Gibbaranea occidentalis</i> Wunderlich, 1989</b> | E (NT)   | 81    | 265      | 346             |
| Cheiracanthiidae | <i>Cheiracanthium erraticum</i> (Walckenaer, 1802)     | I        | 9     | 8        | 17              |
| Cheiracanthiidae | <i>Cheiracanthium mildei</i> L. Koch, 1864             | I        | 11(*) | 0        | 11              |
| Clubionidae      | <i>Clubiona terrestris</i> Westring, 1851              | I        | 23    | 2        | 25              |
| Clubionidae      | <i>Porrhoclubiona decora</i> (Blackwall, 1859)         | N        | 25    | 19       | 44              |
| Clubionidae      | <i>Porrhoclubiona genevensis</i> (L. Koch, 1866)       | I        | 18    | 20       | 38              |
| Dictynidae       | <i>Emblyna açorensis</i> Wunderlich, 1992              | E (NT)   | 5     | 1        | 6               |
| Dictynidae       | <b><i>Lathys dentichelis</i> (Simon, 1883)</b>         | N        | 61    | 244      | 305             |
| Dictynidae       | <i>Nigma puella</i> (Simon, 1870)                      | I        | 8     | 1        | 9               |
| Dysderidae       | <b><i>Dysdera crocata</i> C. L. Koch, 1838</b>         | I        | 108   | 79       | 187             |
| Linyphiidae      | <b><i>Acorigone açorensis</i> (Wunderlich, 1992)</b>   | E (VU)   | 152   | 200      | 352             |
| Linyphiidae      | <i>Canariphantes açorensis</i> (Wunderlich, 1992)      | E (VU)   | 22    | 18       | 40              |
| Linyphiidae      | <i>Erigone atra</i> Blackwall, 1833                    | I        | 1     | 1        | 2               |

| Family         | Species   | Colonis. | Pico | Terceira | Total Abundance |
|----------------|---|----------|------|----------|-----------------|
| Linyphiidae    | <i>Erigone autumnalis</i> Emerton, 1882                   | I        | 0    | 2        | 2               |
| Linyphiidae    | <b><i>Microlinyphia johnsoni</i> (Blackwall, 1859)</b>    | N        | 117  | 160      | 277             |
| Linyphiidae    | <i>Minicia floresensis</i> Wunderlich, 1992               | E (VU)   | 2    | 9        | 11              |
| Linyphiidae    | <i>Neriere clathrata</i> (Sundevall, 1830)                | I        | 1    | 0        | 1               |
| Linyphiidae    | <i>Pallidophantes schmitzi</i> (Kulczynski, 1899)         | N        | 4    | 0        | 4               |
| Linyphiidae    | <i>Pelecopsis parallela</i> (Wider, 1834)                 | I        | 0    | 1        | 1               |
| Linyphiidae    | <i>Porrhomma borgesii</i> Wunderlich, 2008                | E (VU)   | 4    | 1        | 5               |
| Linyphiidae    | <i>Prinerigone vagans</i> (Audouin, 1826)                 | I        | 0    | 1        | 1               |
| Linyphiidae    | <b><i>Savigniorhipis acoreensis</i> Wunderlich, 1992</b>  | E (VU)   | 25   | 607      | 632             |
| Linyphiidae    | <b><i>Tenuiphantes miguelensis</i> (Wunderlich, 1992)</b> | N        | 912  | 38       | 950             |
| Linyphiidae    | <b><i>Tenuiphantes tenuis</i> (Blackwall, 1852)</b>       | I        | 243  | 57       | 300             |
| Linyphiidae    | <i>Walckenaeria grandis</i> (Wunderlich, 1992)            | E (VU)   | 7    | 45       | 52              |
| Lycosidae      | <i>Pardosa acoreensis</i> Simon, 1883                     | E (LC)   | 1    | 0        | 1               |
| Mimetidae      | <i>Ero furcata</i> (Villers, 1789)                        | I        | 7    | 86       | 93              |
| Pisauridae     | <i>Pisaura acoreensis</i> Wunderlich, 1992                | E (NT)   | 9    | 25       | 34              |
| Salticidae     | <b><i>Macaroeris cata</i> (Blackwall, 1867)</b>           | N        | 19   | 160      | 179             |
| Salticidae     | <i>Macaroeris diligens</i> (Blackwall, 1867)              | N        | 1    | 7        | 8               |
| Salticidae     | <i>Neon acoreensis</i> Wunderlich, 2008                   | E (VU)   | 1    | 0        | 1               |
| Segestriidae   | <i>Segestria florentina</i> (Rossi, 1790)                 | I        | 0    | 1        | 1               |
| Tetragnathidae | <i>Metellina merianae</i> (Scopoli, 1763)                 | I        | 8    | 6        | 14              |
| Tetragnathidae | <i>Leucognatha acoreensis</i> (Wunderlich, 1992)          | E (VU)   | 20   | 134      | 154             |
| Theridiidae    | <i>Cryptachaea blattea</i> (Urquhart, 1886)               | I        | 27   | 121      | 148             |
| Theridiidae    | <i>Lasaeola oceanica</i> Simon, 1883                      | E (LC)   | 0    | 2        | 2               |
| Theridiidae    | <i>Parasteatoda tepidarium</i> (C. L. Koch, 1841)         | I        | 0    | 20       | 20              |
| Theridiidae    | <b><i>Rugathodes acoreensis</i> Wunderlich, 1992</b>      | E (NT)   | 148  | 632      | 780             |
| Theridiidae    | <i>Steatoda grossa</i> (C. L. Koch, 1838)                 | I        | 3    | 3        | 6               |
| Theridiidae    | <i>Steatoda nobilis</i> (Thorell, 1875)                   | I        | 7    | 9        | 16              |
| Theridiidae    | <i>Theridion musivivum</i> Schmidt, 1956                  | N        | 0    | 2        | 2               |
| Thomisidae     | <i>Xysticus cor</i> Canestrini, 1873                      | N        | 18   | 6        | 24              |
| Zoropsidae     | <i>Zoropsis spinimana</i> (Dufour, 1820)                  | I        | 2    | 0        | 2               |

The ten most abundant species are composed mostly of endemic or native non-endemic species and only two exotic species (*Tenuiphantes tenuis* (Blackwall, 1852) and *Dysdera crocata* C. L. Koch, 1838). The most abundant species were the endemic linyphiid *Tenuiphantes miguelensis* with 950 specimens (776 [81%] adults) (Fig. 5) and the endemic theridiid *Rugathodes acoreensis* with 780 specimens (293 [38%] adults) (Fig. 6). Linyphiidae was the richest and most abundant family with 15 (33%) species and 2630 (51%) specimens (Table 2).



Figure 5. [doi](#)

*Tenuiphantes miguelensis* (Wunderlich, 1992), Left: Female/Right: Male, Credit: Sébastien Lhoumeau.

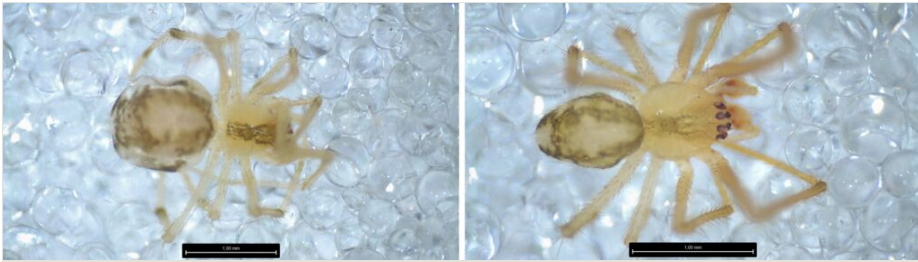


Figure 6. [doi](#)

*Rugathodes acoreensis* Wunderlich, 1992, Left: Female/Right: Male, Credit: Sébastien Lhoumeau.

*Cheiracanthium mildei* L. Koch, 1864 is a new record for Pico Island (Fig. 7).



Figure 7. [doi](#)

*Cheiracanthium mildei* L. Koch, 1864, Left: Male Right: Detail of male pedipalp, Credit: Jørgen Lissner.

Both on Terceira and Pico Islands, the abundance of adults gradually increased from autumn to summer, with the highest abundance occurring in summer and the lowest in autumn. On Terceira Island, we collected more juveniles than adults in all seasons, except Spring and there were two peaks of abundance in winter and in summer (Fig. 8). On Pico Island, the abundance of juveniles is lower than that of the adults for each season.



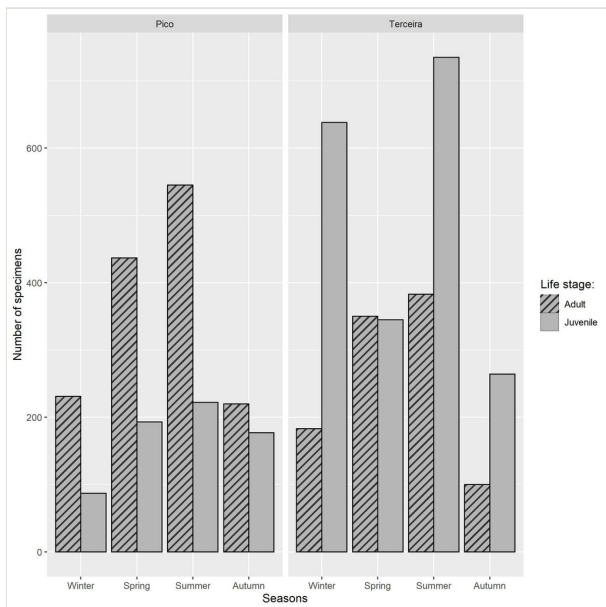


Figure 8. [doi](#)

Total number of specimens collected by season during the 2019-2022 sampling period (note: from winter 2020 to autumn 2021 on Terceira and from winter 2019 to autumn 2021 in Pico).

We observed a slight increase in the overall abundance of the number of specimens during years of sampling, for both Islands. Such increase was more evident on Pico Island than on Terceira Island where we found a peak of abundance in 2013 followed by a drop until 2015. Finally, species abundance on both Islands is globally similar (Fig. 9). This increase can be the consequence of new exotic species sampled.

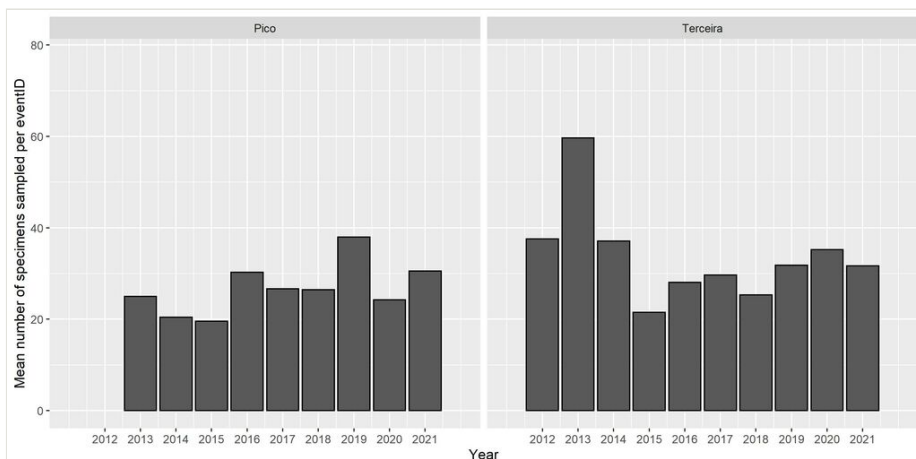


Figure 9. [doi](#)

Mean number of specimens collected by year during the 2012-2021 sampling period.

## Discussion

We analysed all available data on the two target islands – the new data collected between 2019-2021 and those from Costa and Borges (2021) – to obtain a long-term view on their forest spider assemblages. As specified previously, we considered only Event ID that were linked to only one season of sampling (about 90 days).

The use of SLAM traps for long term monitoring in native forest provides good abundance data for spiders amongst a wide variety of families (Table 3). Previous analysis of the sampling strategy revealed a sample completeness of almost 100% for the overall arthropod communities between 2013 and 2018 (Borges et al. 2020).

Table 3.

The list of all species sampled between 2012 and 2022, mentioning the family, colonisation status (E - endemic from Azores; N - native non-endemic; I - exotic introduced species), IUCN status for the endemic species (VU - Vulnerable; NT - Near Threatened; LC - Least Concern) indication of overall abundance (adults + juveniles) in the two studied islands and total abundance. The ten most abundant species are in bold.

| Family           | Species  | Colonis. | Pico | Terceira | Grand total |
|------------------|--|----------|------|----------|-------------|
| Agelenidae       | <i>Tegenaria domestica</i> (Clerck, 1757)              | I        | 2    | 1        | 3           |
| Agelenidae       | <i>Tegenaria pagana</i> C. L. Koch, 1840               | I        | 0    | 1        | 1           |
| Agelenidae       | <i>Textrix caudata</i> L. Koch, 1872                   | I        | 1    | 42       | 43          |
| Araneidae        | <i>Agalenatea redii</i> (Scopoli, 1763)                | I        | 0    | 2        | 2           |
| Araneidae        | <i>Araneus angulatus</i> Clerck, 1757                  | I        | 0    | 1        | 1           |
| Araneidae        | <b><i>Gibbaranea occidentalis</i> Wunderlich, 1989</b> | E (NT)   | 273  | 1330     | 1603        |
| Araneidae        | <i>Mangora acalypha</i> (Walckenaer, 1802)             | I        | 1    | 0        | 1           |
| Araneidae        | <i>Zygiella x-notata</i> (Clerck, 1757)                | I        | 6    | 0        | 6           |
| Cheiracanthiidae | <i>Cheiracanthium erraticum</i> (Walckenaer, 1802)     | I        | 14   | 40       | 54          |
| Cheiracanthiidae | <i>Cheiracanthium mildei</i> L. Koch, 1864             | I        | 11   | 0        | 11          |
| Clubionidae      | <i>Clubiona terrestris</i> Westring, 1851              | I        | 82   | 3        | 85          |
| Clubionidae      | <i>Porrhoclubiona decora</i> (Blackwall, 1859)         | N        | 102  | 268      | 370         |
| Clubionidae      | <i>Porrhoclubiona genevensis</i> (L. Koch, 1866)       | I        | 27   | 45       | 72          |
| Dictynidae       | <i>Emblyna acoreensis</i> Wunderlich, 1992             | E (NT)   | 7    | 6        | 13          |
| Dictynidae       | <b><i>Lathys dentichelis</i> (Simon, 1883)</b>         | N        | 167  | 1140     | 1307        |
| Dictynidae       | <i>Nigma puella</i> (Simon, 1870)                      | I        | 12   | 11       | 23          |
| Dysderidae       | <i>Dysdera crocata</i> C. L. Koch, 1838                | I        | 213  | 276      | 489         |
| Linyphiidae      | <b><i>Acorigone acoreensis</i> (Wunderlich, 1992)</b>  | E (VU)   | 506  | 836      | 1342        |
| Linyphiidae      | <i>Agyneta decora</i> (O. Pickard-Cambridge, 1871)     | I        | 0    | 4        | 4           |
| Linyphiidae      | <i>Canariphantes acoreensis</i> (Wunderlich, 1992)     | E (VU)   | 46   | 42       | 88          |
| Linyphiidae      | <i>Entelecara schmitzi</i> Kulczynski, 1905            | I        | 0    | 11       | 11          |

| Family         | Species   | Colonis. | Pico | Terceira | Grand total |
|----------------|---|----------|------|----------|-------------|
| Linyphiidae    | <i>Erigone atra</i> Blackwall, 1833                       | I        | 1    | 10       | 11          |
| Linyphiidae    | <i>Erigone autumnalis</i> Emerton, 1882                   | I        | 0    | 3        | 3           |
| Linyphiidae    | <i>Erigone dentipalpis</i> (Wider, 1834)                  | I        | 0    | 5        | 5           |
| Linyphiidae    | <i>Mermessus fradeorum</i> (Berland, 1932)                | I        | 1    | 0        | 1           |
| Linyphiidae    | <b><i>Microlinyphia johnsoni</i> (Blackwall, 1859)</b>    | N        | 203  | 616      | 819         |
| Linyphiidae    | <i>Minicia floresensis</i> Wunderlich, 1992               | E (VU)   | 4    | 22       | 26          |
| Linyphiidae    | <i>Neriere clathrata</i> (Sundevall, 1830)                | I        | 3    | 0        | 3           |
| Linyphiidae    | <i>Oedothorax fuscus</i> (Blackwall, 1834)                | I        | 1    | 3        | 4           |
| Linyphiidae    | <i>Palliduphantes schmitzi</i> (Kulczynski, 1899)         | N        | 27   | 5        | 32          |
| Linyphiidae    | <i>Pelecopsis parallela</i> (Wider, 1834)                 | I        | 0    | 11       | 11          |
| Linyphiidae    | <i>Porrhomma borgesii</i> Wunderlich, 2008                | E (VU)   | 4    | 6        | 10          |
| Linyphiidae    | <i>Prinerigone vagans</i> (Audouin, 1826)                 | I        | 0    | 1        | 1           |
| Linyphiidae    | <b><i>Savigniorrhapis acoreensis</i> Wunderlich, 1992</b> | E (VU)   | 138  | 2983     | 3121        |
| Linyphiidae    | <b><i>Tenuiphantes miguelensis</i> (Wunderlich, 1992)</b> | N        | 1730 | 92       | 1822        |
| Linyphiidae    | <b><i>Tenuiphantes tenuis</i> (Blackwall, 1852)</b>       | I        | 768  | 167      | 935         |
| Linyphiidae    | <i>Walckenaeria grandis</i> (Wunderlich, 1992)            | E (VU)   | 46   | 308      | 354         |
| Lycosidae      | <i>Arctosa perita</i> (Latreille, 1799)                   | I        | 0    | 2        | 2           |
| Lycosidae      | <i>Pardosa acoreensis</i> Simon, 1883                     | E (LC)   | 8    | 20       | 28          |
| Mimetidae      | <i>Ero furcata</i> (Villers, 1789)                        | I        | 14   | 505      | 519         |
| Pholcidae      | <i>Pholcus phalangioides</i> (Fuesslin, 1775)             | I        | 0    | 3        | 3           |
| Pisauridae     | <i>Pisaura acoreensis</i> Wunderlich, 1992                | E (NT)   | 35   | 126      | 161         |
| Salticidae     | <b><i>Macaroeris cata</i> (Blackwall, 1867)</b>           | N        | 53   | 688      | 741         |
| Salticidae     | <i>Macaroeris diligens</i> (Blackwall, 1867)              | N        | 6    | 41       | 47          |
| Salticidae     | <i>Neon acoreensis</i> Wunderlich, 2008                   | E (VU)   | 1    | 5        | 6           |
| Salticidae     | <i>Pseudeuophrys vafra</i> (Blackwall, 1867)              | I        | 0    | 8        | 8           |
| Salticidae     | <i>Salticus mutabilis</i> Lucas, 1846                     | I        | 0    | 6        | 6           |
| Segestriidae   | <i>Segestria florentina</i> (Rossi, 1790)                 | I        | 0    | 5        | 5           |
| Tetragnathidae | <i>Metellina merianae</i> (Scopoli, 1763)                 | I        | 13   | 17       | 30          |
| Tetragnathidae | <b><i>Leucognatha acoreensis</i> (Wunderlich, 1992)</b>   | E (VU)   | 126  | 728      | 854         |
| Theridiidae    | <i>Cryptachaea blattea</i> (Urquhart, 1886)               | I        | 34   | 325      | 359         |
| Theridiidae    | <i>Lasaeola oceanica</i> Simon, 1883                      | E (LC)   | 5    | 12       | 17          |
| Theridiidae    | <i>Parasteatoda tepidariorum</i> (C. L. Koch, 1841)       | I        | 0    | 28       | 28          |
| Theridiidae    | <b><i>Rugathodes acoreensis</i> Wunderlich, 1992</b>      | E (NT)   | 358  | 3969     | 4327        |
| Theridiidae    | <i>Steatoda grossa</i> (C. L. Koch, 1838)                 | I        | 4    | 6        | 10          |
| Theridiidae    | <i>Steatoda nobilis</i> (Thorell, 1875)                   | I        | 100  | 25       | 125         |
| Theridiidae    | <i>Theridion musivivum</i> Schmidt, 1956                  | N        | 17   | 3        | 20          |

| Family     | Species                                  | Colonis. | Pico        | Terceira     | Grand total  |
|------------|--|----------|-------------|--------------|--------------|
| Thomisidae | <i>Xysticus cor</i> Canestrini, 1873     | N        | 48          | 38           | 86           |
| Zoropsidae | <i>Zoropsis spinimana</i> (Dufour, 1820) | I        | 20          | 0            | 20           |
|            | <b>GRAND TOTAL</b>                       |          | <b>5238</b> | <b>14851</b> | <b>20089</b> |

So far, we recorded 36 introduced, 14 endemic and nine native non-endemic species in both Terceira and Pico Islands (see Table 3). Although the indigenous/non-indigenous species ratio is in favour of introduced species, in terms of abundance, indigenous species are the most abundant group in native forests, with 75% of total specimens in Pico and 89% in Terceira.

Accumulation curves computed with all our data show a global increase in the number of species through time (Fig. 10), also observed in Fig. 9. It is mainly due to the rise of introduced species. According to these curves, the majority of indigenous species were recorded in the two first years of the SLAM project, reaching an asymptote. However, the number of exotic species recorded continues to increase. It is in accordance with a recent study focusing on all arthropods across the Azores (Borges et al. 2020), which indicates that exotic species are one of the major causes of biodiversity erosion on islands (Borges et al. 2006, Borges et al. 2019). Further investigation through time series analyses is needed to assess the rate and detection of new introduced species and to properly adapt the conservation management of these areas. It is also necessary to study the temporal variation in species assemblages to detect turnover amongst exotic species that may be caused by limitations to establishment in native forest (lack of pre-adaptation, competitive exclusion, resource availability).

Most of the species simultaneously found on Pico and Terceira Islands share similar abundances (Fig. 11), with some exceptions. Two of the dominant species in Pico were not particularly abundant in Terceira (namely *Tenuiphantes miguelensis* (Wunderlich, 1992) and *Tenuiphantes tenuis* (Blackwall, 1852)). On the other hand, *Rugathodes acoreensis* Wunderlich, 1992 and *Savigniorrhapis acoreensis* Wunderlich, 1992 are relatively more abundant in Terceira than in Pico. The temporal dynamic of the single introduced species, *Tenuiphantes tenuis*, should be monitored. These “exceptional” species and their trend through time could possibly be used as bioindicators to assess the conservation status of native forests in different Azorean Islands, since they are morphologically easily differentiable and highly abundant. This allows a quick identification, with the help of some field guides (like Vieira et al. 2021) and a rapid assessment even by non-specialist people.

Differences in the dominant species on islands might be linked to the micro-habitat preference of such species. Indeed, according to Borges and Wunderlich (2008), *Rugathodes acoreensis*, *Gibbaranea occidentalis* and *Savigniorrhapis acoreensis* are most common at the canopy level, while *Tenuiphantes miguelensis* and *Tenuiphantes tenuis* occur mostly at ground level. Therefore, the structure of the native forest is an important factor that may be impacting the distribution of the arachnofauna, both in terms of plant composition and architecture.

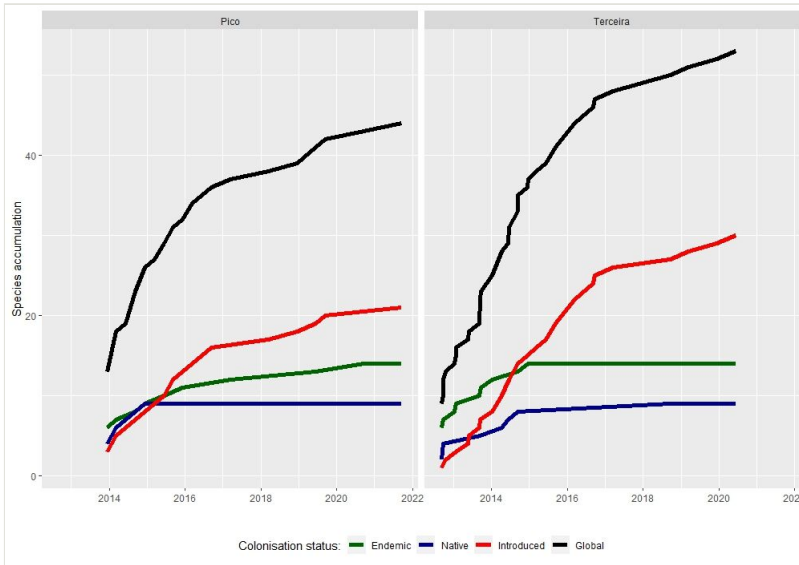


Figure 10. [doi](#)

Species accumulation curves for the period 2012-2021 in the Islands of Pico and Terceira for the total species, but also for the three colonisation status groups: endemics, native-non-endemics and introduced species.

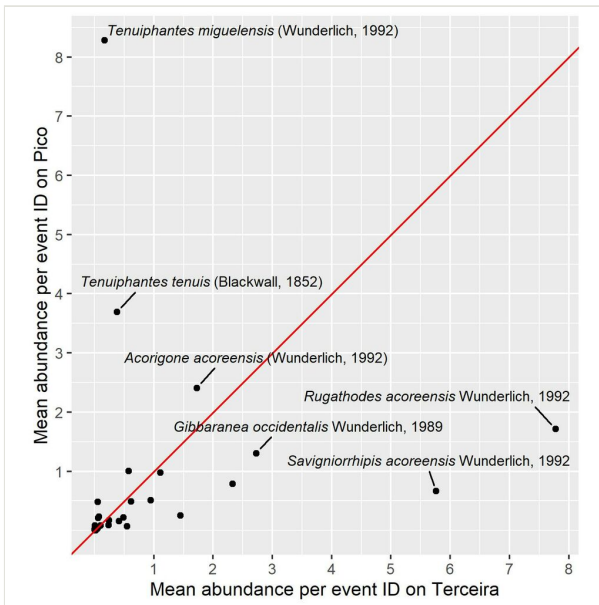


Figure 11. [doi](#)

Scatter plot of mean abundance per event ID of the simultaneously collected species in Pico and Terceira Islands (n = 30 species). The red line represents the theoretical perfect match of abundance between the two Islands.

From a land use perspective, these results can be linked to the size of the native forests' fragments. Indeed, the native forest on Pico Island is more fragmented than on Terceira Island (Borges and Hortal 2009, Triantis et al. 2010).

The majority of the most abundant species show a relatively stable abundance through time (Figs 12, 13). This stability is a positive sign of the ecosystem quality, since indigenous species are dominant in the native forests. However, more data and deeper statistical analysis are needed in future studies to confirm this apparent stability. Interestingly, *T. miguelensis* showed a slow increase of the mean number of specimens per site, but also an increase in the variation around this mean. This dynamic can be an effect of climate change (Ferreira et al. 2016) or land-use change in Pico Island (Gil et al. 2018). Finally, *Tenuiphantes tenuis*, the only dominant exotic species in the dataset, exhibits a hump-shaped variation of abundance in Pico Island, where a peak of abundance was observed in 2017, when an average of circa 15 specimens per site were sampled. Its abundance is now decreasing, which is a positive observation. Particular attention should be given to this species to determine whether the trend will persist over time, as this species has already been able to successfully colonise other Macaronesia islands (Cardoso and Crespo 2008, Nuria 2010), being one of the dominant species of epigeal spiders found in Madeira native forests (Boieiro et al. 2018).

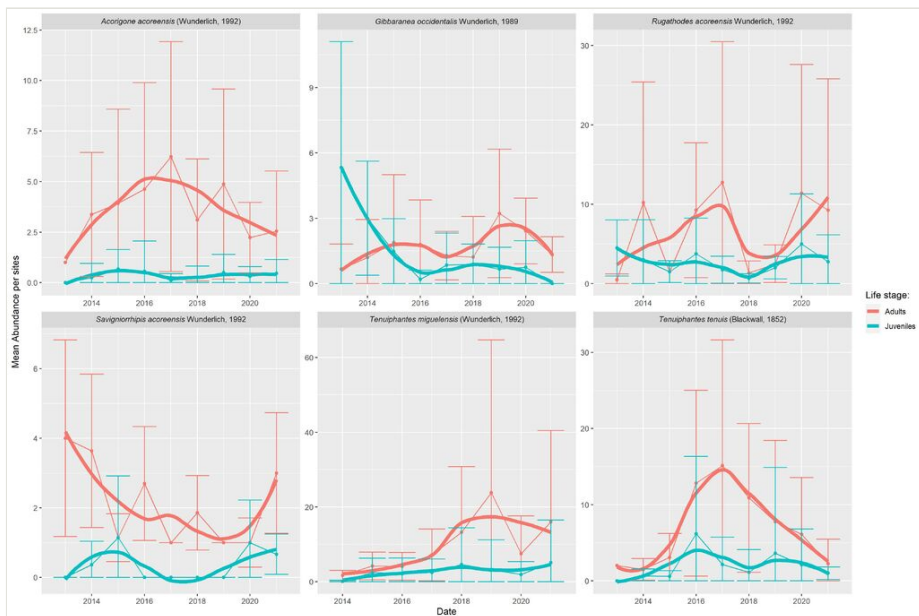


Figure 12. [doi](#)

Time series of the six species showing significant differences in abundance between the two Islands (Pico Island populations).

The SLAM Trap sampling method is fully in accordance with the need of improving arachnofauna knowledge in terms of seasonal abundance and distribution. This kind of

project should be continued to better understand the dynamic of spiders, as well as other arthropod taxa in the native forest of the Azores. Moreover, such data can also now be compared with data from other habitats like disturbed forests (Borges et al. 2022a), touristic trails (Carvalho et al. 2021), agroecosystem (Borges et al. 2021) or other disturbed habitats (Marcelino et al. 2021). The characteristics of the arachnofauna, especially species composition and abundance, can also be used to assess the habitat quality through the computation of Indices of Biotic Integrity (e.g. Cardoso et al. 2007). Additionally, these data can be useful when modelling the trends of communities through time and to prevent possible threats, mainly referring to the introduction of exotic species and extinction risk.

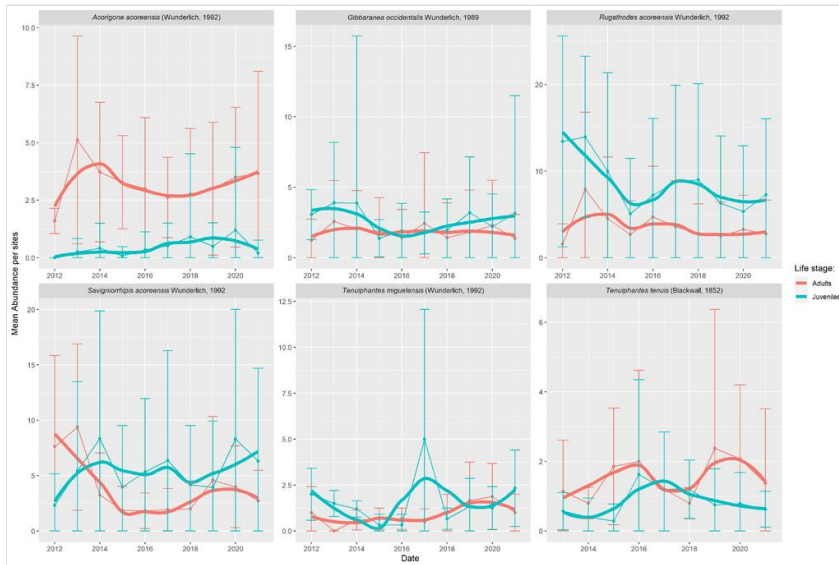


Figure 13. [doi](#)

Time series of the six species showing significant differences in abundance between the two Islands (Terceira Island populations).

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## Author contributions

SL: Laboratory work; Data Curation; Darwin Core dataset preparation; Formal analysis and interpretation; Paper writing.

IRA, MB, PC, RC, RG, JMO, FR, AMCS: Paper revision; interpretation.

PAVB: Conceptualisation; Methodology; Research (field and laboratory work); Resources; Data Curation; Darwin Core dataset preparation; Formal analysis and interpretation; Paper writing.

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