Standardised inventories of spiders (Arachnida, Araneae) on touristic trails of the native forests of the Azores (Portugal)

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Abstract

Background

The sharp increase in tourist visitation of the Azores Archipelago from 2015 onwards raised concerns about the impacts of recreational tourism on native habitats. In response, a project was financed by the Azorean Government to investigate the drivers of biodiversity erosion associated with recreational tourism. Here, we present the data on spider biodiversity found on trails located within the native Azorean forests as they are home to several endemic species of great conservation value. We applied an optimised and standardised sampling protocol (COBRA) in twenty-three plots located in five trails on
Terceira and São Miguel Islands and assessed diversity and abundance of spider species at different distances from the trail head and the trail itself.

**New information**

Of the 45 species (12435 specimens) collected, 13 were endemic to the Azores (9690 specimens), 10 native non-endemic (2047 specimens) and 22 introduced (698 specimens). This database will be the baseline of a long-term monitoring project for the assessment of touristic impacts on native forest trails. This methodology can also be used on other habitats and biogeographical regions.

**Keywords**

Arthropoda, hiking, recreation ecology, Macaronesia, endemic species, checklist

**Introduction**

In the Azores, as in many other temperate, semi-tropical and tropical islands, historical patterns of habitat loss have typically resulted in lowland clearance, meaning that the last remnants of the pre-human pristine forest that covered the major parts of oceanic islands are in the mountain areas (Gaspar et al. 2011). The communities of these mountain forests are of critical importance for the protection of current island biodiversity since they are home to many Azorean endemic species (Borges et al. 2017, Borges et al. 2018, Malumbres-Olarte et al. 2019) and provide a variety of ecosystem services (e.g. water storage, erosion control, pollination, pest-control, food supply, recreation and tourism), contributing to the local economy and welfare (Fernandez-Palacios et al. 2017).

The recent increase in recreational tourist activities in native habitats of the Azores (SREA 2018) raises concerns about the use of trails being a threat to the already imperilled native forest biodiversity. Hiking trails in particular have been found to be promoting the spread of invasive plants (Barros and Pickering 2014), which may cause adverse cascading effects on arthropods.

The spider communities of the Azores are exceptionally well known due to ongoing inventorying and monitoring projects carried out since 1999 (Borges et al. 2016, Emerson et al. 2017, Malumbres-Olarte et al. 2019). The protocol used in NETBIOME ISLANDBIODIV and in this project is part of a long term monitoring proposal for oceanic islands (Borges et al. 2018).

**General description**

**Purpose:** We aimed to characterise the richness and abundance of spiders in areas surrounding trails in native Azorean forest and to assess if the distance to the head of
hiking trails or to the trail itself explains shifts in spider community composition, compared
with areas undisturbed by tourists.

**Project description**

**Title:** Spiders (Arachnida, Araneae) from Azorean native forest trails

**Personnel:** Rui Carvalho led the sampling in the field with the participation of Alejandra Ros-Prieto, Cândida Ramos, Fernando Pereira, Jagoba Malumbres-Olarte, Maria T. Ferreira, Mário Boieiro, Lucas Lamelas-López and Paulo A. V. Borges.

**Study area description:** We focused on the Azorean forests of Terceira and São Miguel Islands, as they have pedestrian trails going through native forests with a relevant level of visitation (Fig. 1). Terceira Island (area: 400.6 km²; elevation: 1021.14 m) and São Miguel Island (area: 744.6 km²; elevation: 1103 m) are two of the nine islands from the Azores Archipelago. The climate in the Azores is temperate oceanic, with regular and abundant rainfall, with high levels of relative humidity and persistent winds, mainly during winter and autumn seasons. Terceira Island is known for the presence of some very important pristine areas at high elevation (Gaspar et al. 2011).

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**Sampling methods**

**Study extent:** We selected six 50 x 50 m sampling sites in native forest patches along the studied trails, at increasing distances from the trail head: 0 m, 50 m and 250 m. Another sampling site, termed Max, was set independently from distance - it was located where the forest adjacent to the trail was most pristine. Finally, two control sites were selected at 50 m and 250 m from the closest trail point (Table 1). This setup is repeated at each trail. In Terceira, the Control 250 data were retrieved from NETBIOME-ISLANDBIODIV samples from 2012 (see Malumbres-Olarte et al. 2019).

| Island | Fragment | Trail | Sampling sites | Latitude  | Longitude |
|--------|----------|-------|----------------|-----------|-----------|
| Terceira | Santa Bárbara | Lagoinha | 0 | 38.7496 | -27.3340 |
| Terceira | Santa Bárbara | Lagoinha | 50 | 38.74946 | -27.3333 |
| Terceira | Santa Bárbara | Lagoinha | 250 | 38.7497 | -27.3320 |
| Island   | Fragment     | Trail       | Sampling sites | Latitude | Longitude |
|----------|--------------|-------------|----------------|----------|-----------|
| Terceira | Santa Bárbara| Lagoinha    | Control 50     | 38.7496  | -27.3304  |
| Terceira | Santa Bárbara| Lagoinha    | Control 250    | 38.7521  | -27.3313  |
| Terceira | Santa Bárbara| Mistérios Negros | 0          | 38.7383  | -27.2786  |
| Terceira | Santa Bárbara| Mistérios Negros | 50         | 38.7383  | -27.2789  |
| Terceira | Santa Bárbara| Mistérios Negros | 250        | 38.7390  | -27.2801  |
| Terceira | Santa Bárbara| Mistérios Negros | Max        | 38.7394  | -27.2824  |
| Terceira | Santa Bárbara| Mistérios Negros | Control 50  | 38.7390  | -27.2819  |
| Terceira | Santa Bárbara| Mistérios Negros | Control 250 | 38.7372  | -27.2899  |
| Terceira | Santa Bárbara| Santa Bárbara | 0            | 38.7322  | -27.3111  |
| Terceira | Santa Bárbara| Santa Bárbara | 50           | 38.7325  | -27.3106  |
| Terceira | Santa Bárbara| Santa Bárbara | 250          | 38.7336  | -27.3088  |
| Terceira | Santa Bárbara| Santa Bárbara | Max          | 38.7347  | -27.3073  |
| Terceira | Santa Bárbara| Santa Bárbara | Control 50    | 38.7348  | -27.3090  |
| Terceira | Santa Bárbara| Santa Bárbara | Control 250   | 38.7356  | -27.3074  |
| Terceira | Guilherme Moniz| Guilherme Moniz | 0          | 38.7087  | -27.1904  |
| São Miguel| Pico da Vara | Malhadas    | 0             | 37.8170  | -25.1848  |
| São Miguel| Pico da Vara | Malhadas    | 50            | 37.8164  | -25.1855  |
| São Miguel| Pico da Vara | Malhadas    | 250           | 37.8157  | -25.1864  |
| São Miguel| Pico da Vara | Malhadas    | Max           | 37.8163  | -25.1900  |

**Sampling description:** The inventory COBRA (Conservation Oriented Biodiversity Rapid Assessment) protocol (Cardoso 2009) was used at the most pristine area in the studied fragment, firstly to assess whether completeness is sufficient to use the less time-intensive protocols; secondly, in order to be used as alpha and beta diversity baselines (Borges et al. 2018). It is composed of four hours of aerial search, four hours of tree beating, four hours of vegetation sweeping and pitfall sampling using 48 traps. The traps containing propylene glycol were active for 15 days and, during sample collection, they were arranged in groups of four to make 12 sample units. For the remaining sampling areas of each trail, the much less intensive monitoring COBRA protocol was used. It is composed of four hours of aerial search and two hours of beating trees using a drop cloth (see Borges et al. 2018 for details). The COBRA protocol has been proposed as part of standard inventorying and monitoring programmes targeting spiders and beetles and has been used on island and continental ecosystems, from subarctic regions to the tropics (Cardoso 2009, Borges et al. 2018, Malumbres-Olarte et al. 2019, Malumbres-Olarte et al. 2020).
Quality control: All the spider specimens were first sorted into morphospecies by R Carvalho and later identified by a trained taxonomist (one of the authors: PAV Borges).

Geographic coverage

Description: Terceira and São Miguel Islands, Azores, Portugal

Bounding Coordinates: South West [37.579, -27.466], North East [39.045, -25.049]

Taxonomic coverage

Taxa included:

| Rank  | Scientific Name | Common Name |
|-------|-----------------|-------------|
| order | Araneae         | Spiders     |

Traits coverage

Macías-Hernández et al. (2020) published the database of functional traits for all species in the study.
Temporal coverage

Notes: July to August 2012 for the Control 250 samples; July to October 2017 for all other samples.

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: Open Data Commons Attribution License

IP rights notes: CC-BY 4.0

Data resources

Data package title: Diversity of Spiders from Azorean Trails

Resource link: https://www.gbif.org/dataset/76e75816-b0dc-4460-9de2-294f3e05ad83

Alternative identifiers: https://doi.org/10.15468/wgnw57

Number of data sets: 1

Data set name: Diversity of Spiders from Azorean Trails

Download URL: http://ipt.gbif.pt/ipt/resource?r=spiders_of_azorean_trails

Data format: Darwin Core Archive

Data format version: version 1

Description: The following data table includes all the records for which a taxonomic identification of the species was possible. The dataset submitted to GBIF (Global Biodiversity Information Facility) is structured as a sample event dataset, with two tables: event (as core) and occurrences. The data in this sampling event resource have 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 194 records (eventID) and the occurrences file 1290 records (occurrenceID). This IPT (integrated publishing toolkit) archives the data and thus serves as the data
repository. The data and resource metadata are available for download from Carvalho et al. (2021).

| Column label          | Column description                                                                 |
|-------------------|-----------------------------------------------------------------------------------|
| Table of Sampling Events | Table with sampling events data (beginning of table)                           |
| id                | Unique identification code for sampling event data                                |
| eventID           | Identifier of the events, unique for the dataset                                  |
| stateProvince     | Name of the region of the sampling site                                           |
| 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                                      |
| municipality      | Municipality of the sampling site                                                 |
| decimalLongitude  | Approximate centre point decimal longitude of the field site in GPS coordinates   |
| decimalLatitude   | Approximate centre point decimal latitude of the field site in GPS coordinates     |
| geodeticDatum     | The ellipsoid, geodetic datum or spatial reference system (SRS) upon which the    |
| coordinateUncertaintyInMetres | Uncertainty of the coordinates of the centre of the sampling plot  |
| 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.                                                |
| locationID        | Identifier of the location                                                       |
| locationRemarks   | Details on the locality site                                                     |
| locality          | Name of the locality                                                             |
| minimumElevationInMetres | The lower limit of the range of elevation (altitude, usually above sea level), |
| maximumElevationInMetres | The upper limit of the range of elevation (altitude, usually above sea level),  |
| habitat           | The surveyed habitat                                                             |
| year              | Year of the event                                                                |
| month             | Month of the event                                                               |
| day               | Day of the event                                                                 |
| eventRemarks      | Comments or notes about the Event                                                |
| Term                  | Description                                                                 |
|----------------------|-----------------------------------------------------------------------------|
| 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                                            |
| samplingEffort       | The amount of time of each sampling                                          |
| fieldNumber          | An identifier given to the event in the field. Often serves as a link between field notes and the Event. |
| eventDate            | Date or date range the record was collected                                  |
| Table of Species Occurrence | Table with species abundance data (beginning of new table)                |
| id                   | Unique identification code for species abundance data                       |
| 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                                                |
| dynamicProperties    | The name of the scientific project funding the sampling                      |
| occurrenceID         | Identifier of the record, coded as a global unique identifier               |
| recordedBy           | Name of the person who performed the sampling of the specimens              |
| individualCount      | Total number of individuals captured                                        |
| 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: ‘naturalised’, ‘introduced’, ‘endemic’, “unknown” |
| eventID              | Identifier of the events, unique for the dataset                            |
| scientificName       | Complete scientific name including author and year                           |
| kingdom              | Kingdom name                                                                |
| phylum               | Phylum name                                                                  |
| class                | Class name                                                                   |
| order                | Order name                                                                   |
| family               | Family name                                                                  |
Results

We collected a total of 12435 specimens belonging to 45 species of spiders. A total of 13 species are endemic to the Azores Archipelago (9690 specimens), 10 are native non-endemic (2047 specimens) and 22 are introduced (698 specimens) (Table 2, Table 3).

| Trail / Sampling Area | Endemic Species richness | Endemic Abundance | Native Species richness | Native Abundance | Introduced Species richness | Introduced Abundance |
|-----------------------|--------------------------|-------------------|------------------------|-----------------|---------------------------|---------------------|
| Lagoinha 0            | 5                        | 479               | 10                     | 62              | 5                         | 7                   |
| Lagoinha 50           | 7                        | 364               | 14                     | 91              | 7                         | 15                  |
| Lagoinha 250          | 5                        | 534               | 12                     | 64              | 7                         | 11                  |
| Lagoinha Control 50   | 9                        | 419               | 15                     | 174             | 3                         | 5                   |
| Lagoinha Control 250  | 5                        | 417               | 14                     | 187             | 10                        | 27                  |
| Mistérios Negros 0    | 6                        | 466               | 17                     | 94              | 14                        | 33                  |
| Mistérios Negros 50   | 8                        | 421               | 15                     | 55              | 7                         | 14                  |
| Mistérios Negros 250  | 8                        | 418               | 18                     | 119             | 18                        | 184                 |
| Mistérios Negros Max  | 9                        | 628               | 20                     | 64              | 15                        | 57                  |
| Mistérios Negros Control 50 | 6 | 993 | 13 | 187 | 10 | 27 |
| Mistérios Negros Control 250 | 9 | 394 | 17 | 128 | 7 | 12 |
| Santa Bárbara 0       | 8                        | 325               | 13                     | 17              | 2                         | 12                  |
| Santa Bárbara 50      | 7                        | 230               | 13                     | 38              | 5                         | 22                  |
| Santa Bárbara 250     | 6                        | 417               | 11                     | 43              | 3                         | 7                   |

Table 2. Diversity and abundance for the collected species, according to biogeographic origin and sampling area.
| Trail / Sampling Area | Species richness | Abundance | Species richness | Abundance | Species richness | Abundance |
|-----------------------|------------------|-----------|------------------|-----------|------------------|-----------|
| Santa Bárbara Max     | 8                | 410       | 15               | 40        | 4                | 6         |
| Santa Bárbara Control 50 | 7            | 463       | 16               | 26        | 6                | 10        |
| Santa Bárbara Control 250 | 10          | 405       | 17               | 75        | 8                | 17        |
| Guilherme Moniz 0     | 8                | 903       | 26               | 220       | 20               | 57        |
| Malhadas 0            | 6                | 148       | 18               | 41        | 13               | 20        |
| Malhadas 50           | 7                | 245       | 22               | 63        | 19               | 79        |
| Malhadas 250          | 5                | 232       | 14               | 43        | 10               | 30        |
| Malhadas Max          | 7                | 378       | 22               | 217       | 35               | 46        |

Table 3.
Spider species abundance in each study area and their biogeographic origin. Abbreviations: Biogeographic origin (Biog. origin); Endemic (END); Introduced (INT); Native (NAT).
| Family      | Scientific name                        | Biog. origin | Lagoinha Negros | Mistérios Negros | Santa Bárbara | Guilherme Moniz | Malhadas |
|------------|----------------------------------------|--------------|-----------------|------------------|---------------|-----------------|----------|
| Linyphiidae| *Acorigone acoreensis* (Wunderlich, 1992) | END          | 5               | 4                | 11            | 1               | 0        |
| Linyphiidae| *Agyneta decora* (O.P.-Cambridge, 1871) | INT          | 0               | 0                | 3             | 0               | 2        |
| Linyphiidae| *Canariaphantes acoreensis* (Wunderlich, 1992) | END          | 12              | 17               | 91            | 0               | 0        |
| Linyphiidae| *Erigone atra* Blackwall, 1833          | INT          | 1               | 0                | 0             | 0               | 1        |
| Linyphiidae| *Erigone autumnalis* Emerton, 1882      | INT          | 0               | 1                | 0             | 1               | 1        |
| Linyphiidae| *Erigone dentipalpis* (Wider, 1834)    | INT          | 0               | 0                | 0             | 0               | 1        |
| Linyphiidae| *Meioneta fuscipalpa* (C.L. Koch, 1836) | INT          | 0               | 0                | 0             | 1               | 0        |
| Linyphiidae| *Mermessus bryantae* (Ivie & Barrows, 1935) | INT          | 0               | 1                | 0             | 0               | 0        |
| Linyphiidae| *Mermessus fradeorum* (Berland, 1932)  | INT          | 0               | 0                | 0             | 2               | 0        |
| Linyphiidae| *Microlinyphia johnsoni* (Blackwall, 1859) | NAT          | 16              | 19               | 12            | 16              | 0        |
| Linyphiidae| *Minicia floresensis* Wunderlich, 1992  | END          | 1               | 0                | 3             | 0               | 7        |
| Linyphiidae| *Neriene clathrata* (Sundevall, 1830)  | INT          | 0               | 0                | 0             | 0               | 2        |
| Linyphiidae| *Oedothorax fuscus* (Blackwall, 1834)  | INT          | 0               | 0                | 0             | 1               | 1        |
| Linyphiidae| *Palliduphantes schmitzi* (Kulczynski, 1899) | NAT          | 2               | 0                | 3             | 0               | 0        |
| Linyphiidae| *Porromma borgesi* Wunderlich, 2008    | END          | 0               | 1                | 1             | 0               | 0        |
| Linyphiidae| *Primerigone vagans* (Audouin, 1826)   | INT          | 0               | 0                | 0             | 1               | 4        |
| Family          | Scientific name                                      | Biog. origin | Lagoinha Negros | Santa Bárbara | Guilherme Moniz | Malhadas |
|----------------|------------------------------------------------------|--------------|-----------------|---------------|-----------------|----------|
| Linyphiidae    | Savigniorrhipsis acoreensis Wunderlich, 1992         | END          | 430             | 537           | 384             | 60       | 184      |
| Linyphiidae    | Tenuiphantes miguelensis (Wunderlich, 1992)          | NAT          | 97              | 22            | 20              | 1        | 46       |
| Linyphiidae    | Tenuiphantes tenuis (Blackwall, 1852)                | INT          | 3               | 2             | 2               | 1        | 14       |
| Linyphiidae    | Walckenaeria grandis (Wunderlich, 1992)              | END          | 1               | 0             | 11              | 0        | 0        |
| Lycosidae      | Pardosa acorensis Simon, 1883                        | END          | 3               | 4             | 45              | 0        | 72       |
| Mimetidae      | Ero furcata (Villers, 1789)                         | INT          | 4               | 23            | 0               | 2        | 10       |
| Pisauridae     | Pisaura acorensis Wunderlich, 1992                  | END          | 3               | 13            | 57              | 8        | 21       |
| Salticidae     | Macaroeris cata (Blackwall, 1867)                   | NAT          | 97              | 55            | 16              | 28       | 63       |
| Salticidae     | Macaroeris diligens (Blackwall, 1867)               | NAT          | 0               | 0             | 1               | 0        | 0        |
| Salticidae     | Neon acorensis Wunderlich, 2008                      | END          | 0               | 2             | 0               | 1        | 0        |
| Tetragnathidae | Metellina merianaе (Scopoli, 1763)                  | INT          | 5               | 146           | 15              | 35       | 78       |
| Tetragnathidae | Sancus acorensis (Wunderlich, 1992)                 | END          | 831             | 621           | 974             | 165      | 505      |
| Theridiidae    | Cryptachaea blatteа (Urquhart, 1886)                | INT          | 0               | 0             | 1               | 1        | 1        |
| Theridiidae    | Lasaeola oceanica Simon, 1883                       | END          | 53              | 105           | 4               | 2        | 6        |
| Theridiidae    | Rhomphaea nasica (Simon, 1873)                       | INT          | 0               | 0             | 0               | 1        | 0        |
| Theridiidae    | Rugathodes acorensis Wunderlich, 1992               | END          | 61              | 263           | 304             | 103      | 68       |
| Theridiidae    | Steatoda nobilis (Thorell, 1875)                    | INT          | 1               | 6             | 1               | 9        | 11       |
The five most abundant species were *Gibbaranea occidentalis* Wunderlich, 1989 (3635 specimens) (endemic), *Sancus acreensis* (Wunderlich, 1992) (3096 specimens) (endemic), *Savigniorrhapis acreensis* Wunderlich, 1992 (1595 specimens) (endemic), *Lathys dentichelis* (Simon, 1883) (1361 specimens) (native non-endemic) and *Rugathodes acreensis* Wunderlich, 1992 (799 specimens) (endemic). These five species accounted for 84% of all individuals of the total. The most abundant introduced species was *Metellina meriana* Scopoli, 1763 with 279 specimens.

This database will be used in future studies where the variation of the spider communities amongst the various sites will be tested against variables that are known to be relevant for understanding the impact of touristic activities, such as the distance to the trail head and the distance from the sampling area to the nearest trail point. We will use GLMMs, where the trail identity will be used as random effect and the edge effect will be added as an independent variable in order to avoid spurious results. This will respond to the questions of whether there is a detectable effect of recreational activities on the spiders community structure and what is contributing to this ecological shift.

Contrary to Canary Islands and Madeira, the Azorean Archipelago has not yet experienced continuous high levels of visitation. This sampling was made at the early times of a noticeably higher touristic pressure in the Azores and will allow for future monitoring events to have a comparable baseline and better isolate the touristic factors from others, thus improving the management outlook on tourism's ecological effects on spider communities.

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Author contributions

RC, PC and PAVB conceived the study design and the sampling programme. RC, PAVB, CR, MTF, LLL, MB, JMO, ARP and FP performed spider sampling. PAVB and RC performed spider identification. RC analysed the data and led the writing. All authors contributed to the final version of the manuscript.

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