Versión española

The biodiversity of terrestrial arthropods in Azores

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1. The Azores archipelago

The Azores are a volcanic archipelago located in the middle of North Atlantic Ocean. Together with the archipelagos of Madeira, Selvagens, Canary Islands and Cabo Verde, they are part of Macaronesia, the "happy islands" (Fernández-Palacios, 2010). The Azorean Islands were discovered by Portuguese navigators in 1427 (Santa Maria), Flores and Corvo being the last islands to be found in 1452. However, according to old maps its existence was previously known. It is believed that the archipelago received its name from birds that were common in these islands either the Goshawk (Açor in Portuguese) or a local subspecies of Buzzard (*Buteo buteo rothschildi*) that the sailors erroneously identified as goshawks (Frutuoso, 1963).

The archipelago is composed by nine main islands and some small islets. The islands are divided in three groups: the eastern group with Santa Maria, São Miguel and Formigas islets, the central group with Terceira, Graciosa, São Jorge, Pico and Faial and the western group composed by Flores and Corvo (Fig. 1). The Azores are located at the triple junction of the Eurasian, African and American plates roughly between the coordinates 37° to 40° N latitude and 25° to 31° W longitude. The archipelago is situated over two tectonic plates: the westernmost islands of Flores and Corvo lie on the American plate and are separated from the other islands by the Mid-Atlantic Ridge; the other seven islands are located on a large triangular plateau with a complicated structure known as "Azores Microplate".

The Azores are distanced from the Iberian Peninsula by 1,584 km, calculated from Cabo da Roca (the most westerly point of the European continent), 980 km from Madeira and 1695 km from Morocco (Casablanca). Within the archipelago, Corvo and Santa Maria are the two islands farthest apart, separated by about 615 km. Curiously, Corvo lies approximately at the same distance from the Iberian Peninsula (Europe) and from Newfoundland (North America).

The nine islands differ greatly in terms of biophysical attributes, namely: geological age, area, highest altitude and number of habitants (Fig. 1). The archipelago is relatively young, Santa Maria being the oldest island (8.1 Myr) and Pico the youngest with only about 0.3 Myr. The largest island is São Miguel (757 km^2), while Corvo presents the smallest area (17 km^2). In terms of human population these two islands also represent the extremes, with São Miguel having the largest population as well as the highest population density (INE, 2012)

The Azorean islands have an oceanic climate: mild and agreeable, with small fluctuations in temperature, large amounts of precipitation and high air humidity. The mean temperature reaches the maximum in August and minimum in February with the mean annual temperature being 17.5 ºC. The local microclimate is strongly affected by the Azorean anticyclone. The particular climatic conditions observed in the Azores makes it possible for each island to present a "cloud-zone forest" at high altitudes (Sjögren, 1990), where a fog interception phenomenon occurs. The resulting horizontal rain has great ecological importance. In these cloud zones the rainfall is high, leaving the air saturated with moisture and the soil waterlogged, leading to anoxia phenomena in the soil. The significant increase in rainfall as well as the dominance of *Sphagnum* species at high altitudes, decreases the pH (Dias, 1989) with a consequent decrease in ecological diversity.

Figure 1. Biophysical information of the Azorean islands. AR – island area, AL – maximum altitude, AG – geological age, HA – Human population according with the 2011 census (INE 2012). Map drawn by Clara Gaspar.

Figure 2. Habitat types found in the Azores: **a**) native forest, **b**) *Cryptomeria japonica* woodland, **c**) semi-natural pasture, **d**) intensive pasture (sown pasture), **e**) peatland, **f**) lake (photos by Paulo A.V. Borges and Pedro Cardoso).

The Azores, despite being an isolated archipelago with ample variation in terms of geological history and a wide range of elevations, have less ecological variation and a more uniform habitat composition between islands than other Macaronesian archipelagos (e.g. Triantis *et al*., 2012). Also the present landscape of these islands was strongly modified by the presence of Man and only small areas, where the orography or the harsh climate made it harder to cultivate, remain with primitive conditions and still have native forest. Currently only 5% of the total area of the archipelago is covered with native forest (Gaspar *et al*., 2008), a habitat that, according with earlier descriptions, covered almost entirely the Azores islands upon their discovery in the XV century (e.g. Triantis *et al*., 2010; Silveira, 2013). According with Dias (1991) the natural vegetation of the Azores can be roughly divided in 7 types (Fig. 2):

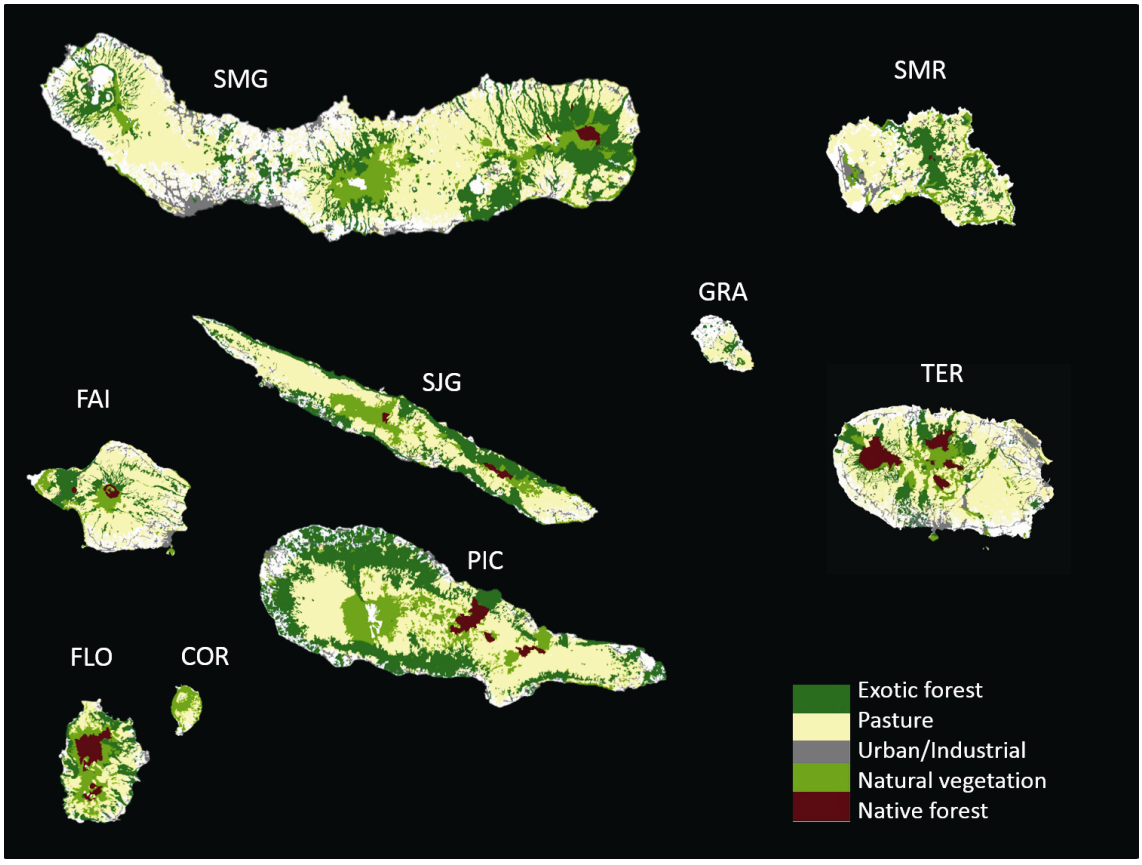


Figure 3. Land use in the nine islands of the Azores. SMR – Santa Maria, SMG – São Miguel, TER – Terceira, SJG – São Jorge, PIC – Pico, FAI – Faial, GRA – Graciosa, FLO – Flores and COR – Corvo. Maps drawn by Enésima Mendonça (source DROTRH, 2008).

a) autochthonous forest, this type of original vegetation is now restricted to higher altitudes and is extremely fragmented, it is dominated by Macaronesian endemic woody species like *Laurus azorica*, *Juniperus brevifolia*, *Ilex perado* subsp. *azorica Vaccinium cylindraceum* and *Erica azorica*, and roughly corresponds to 5% of the archipelago area (Gaspar *et al*., 2008);

b) seral vegetation dominated by endemic species but with some disturbance such as the invasion of exotic species;

c) coastal vegetation, currently very disturbed and dominated by the woody plants *Erica azorica*, *Picconia azorica*, *Morella faya* and several herbaceous plants, notably the now rare *Euphorbia azorica* and *Azorina vidalii*;

d) marshy, lakes and wet peatland including important plant communities of *Sphagnum palustre* and *Eleocharis multicaulis*;

e) woodlands, mainly eucalyptus (*Eucalyptus globulus*) and cryptomeria (*Cryptomeria japonica*) plantations but also pine (*Pinus pinaster*) and mixed woodlands;

f) pastures both intensive (at low and mid altitudes) and semi-natural (at mid to high elevations), which are currently the most abundant vegetation type in the Azores

g) permanent agriculture, mainly fruit trees (orchards) and multiple agriculture greenhouses, crops, etc.

In the Azores, pastures are the predominant land use accounting on average for 42% of each island area; Faial is the island with the highest area of pasture (52%) while Flores and Corvo present the lowest values with 33% and 32% respectively (Cruz *et al*., 2007). In what concerns natural vegetation, Corvo is the island with the highest percentage of natural vegetation (51%) while Graciosa is the one with the lowest (0.38%). However, both islands have no remaining native forest. The destruction of the natural plant cover from Graciosa was eased by the simple orography of the island, which allowed human settlement, field clearing with fire and the development of several crops. Terceira and Flores are the islands where native forest has a bigger expression and they also have the largest and more pristine forest fragments (Gaspar *et al*., 2008; Fig. 3).

The Azores have several protected areas and recently “Parques de ilha” (Island Parks) were established in each island to protect the natural and cultural values of this archipelago. Within each park there are areas with different protection status: natural reserve, natural monument, protected area for habitat or species management, protected landscape and protected area for resource management (Fig. 4). Terrestrial protected areas cover currently 561 km^2 (24% of the total land area of the archipelago). The relative conservation value of 19 forest fragments in seven of the Azorean islands was examined by Gaspar *et al*. (2011), based on Azorean soil epigean arthropod biodiversity and it was concluded that the most pristine areas occur on Terceira (Terra Brava, Biscoito da Ferraria, Caldeira da Serra de Santa Bárbara), Pico

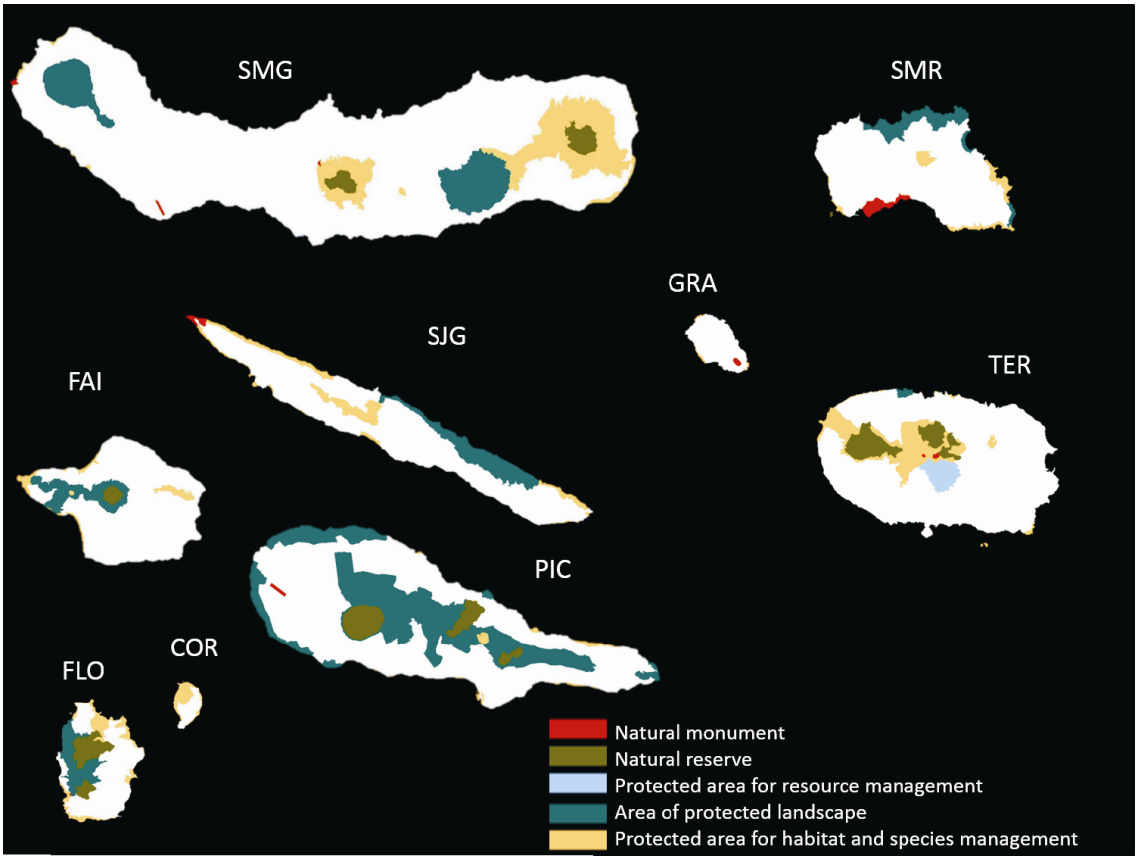


Figure 4. Protected areas in the nine Azorean islands. SMR – Santa Maria, SMG – São Miguel, TER – Terceira, SJG – São Jorge, PIC – Pico, FAI – Faial, GRA – Graciosa, FLO – Flores and COR – Corvo. Maps drawn by Enésima Mendonça (source Direcção Regional do Ambiente).

(Caveiro, Mistério da Prainha) and Flores (Morro Alto e Pico da Sé) islands, while the most disturbed study sites in the Azores are found on the islands of Faial (Cabeço do Fogo), Flores (Caldeiras Funda e Rasa), Pico (Lagoa do Caiado), São Jorge (Pico Pinheiro), São Miguel (Atalhada, Graminhais, Pico da Vara), Santa Maria (Pico Alto) and Terceira (Algar do Carvão, Matela, Pico do Galhardo).

2. History of the knowledge on terrestrial arthropods

Darwin during his voyage aboard the H.M.S. Beagle visited the Azores in 1836. In his diary he compared the countryside of Terceira and São Miguel with areas of England and made no significant comments on the insects from these Islands besides stating that he found “old English friends” (Keynes, 1988). This feeling of “familiarity” together with the fact that this was the last stop before returning home after a long voyage probably made Darwin less enthusiastic in his exploits in the Azores.

Thomas V. Wollaston dedicated much of his life to the study of the insect fauna of the Macaronesian archipelagos, the Coleoptera in particular. However, despite his interest in the Azores, he never collected in this archipelago, probably because of his health problems that made the local climate unsuitable for him to do fieldwork (Machado, 2006).

The first arthropod collections in the Azores were made by H. Drouët and A. Morelet, who visited the islands from April to September of 1857 (Chaves, 1920). The material collected in this expedition is deposited in the Muséum National d'Histoire Naturelle in Paris. The earlier references about the Azorean fauna resulted from this mission, including a report to the Portuguese king (D. Miguel I) referring, among other aspects, 50 beetle species collected during the expedition, including a new endemic *Laparocerus* (Drouët, 1858). The results of this expedition were published between 1859 and 1861 in the journal *Révue et Magasin de Zoologie*, and the books *Elements de la faune Açoréens* and *Iles Açores. Notice sur l`Histoire Naturelle des Açores, suivie d´une description des Molusques terrestres de cet archipel* (Drouët, 1859, 1861; Morelet, 1860; Tarnier, 1860) and focused mainly on Coleoptera and Mollusca. Drouët (1859) commented on the vulgarity of the coleopteran fauna of the Azores, in general very similar to what could be found in areas of France, and remarked on the difference between the diversity of the Coleoptera with only one new species, and the Mollusca with about 30 interesting species including many novelties to science.

The interest in the Azores increased after the publication of Darwin’s *Origin of species by Means of Natural Selection* in 1859, because it was believed that these islands could contain transition forms of animals and plants, between the Nearctic and Palearctic regions (Arruda, 2002).

Frederick Godman visited the Azores in 1865 motivated by the fact that this archipelago remained unexplored, contrary to the other Macaronesian archipelagos which had already been studied by Wollas-

ton and other naturalists revealing very interesting findings. Godman sent samples of animals and plants to several specialists and in 1870 published a book presenting the findings: *Natural History of the Azores or Western Islands* (Godman, 1870). This publication has several chapters devoted to different groups of animals and plants and includes updated information on Coleoptera (Crotch, 1870), Hymenoptera and Lepidoptera.

Wallace (1872), in a commentary about Godman's book, refers the striking similarity (80-90%) between the fauna and flora of the Azores and the one found in Europe. A possible explanation had already been suggested by Godman in his book: the strong storms which are frequent in the archipelago may bring many species from Europe to the Azores.

Naturalists like Francisco Arruda Furtado (1854-1887) also contributed to the increase of knowledge on Azorean biodiversity. He was born in São Miguel and after an early enthusiasm about spiders dedicated himself to the study of molluscs, deemed more suitable for zoogeography studies (Arruda, 1994). He sent numerous animal and plant samples to several international specialists and he was the only Portuguese naturalist to correspond with Charles Darwin (Arruda, 2002). His scientific activity was also related with the passage of foreign naturalists by the Azores whom he assisted and corresponded with. Afonso Chaves, another Azorean naturalist, at a time the director of the Municipal Museum at Ponta Delgada, also made several collections, and for instance the Orthoptera he collected were described by Bolívar (1894).

Increased awareness about the Azores was due mainly to Prince Albert I of Monaco which led several scientific expeditions with the *Hirondelle* in 1885, 1887 and 1888, and the *Princess Alice* in 1895, 1896 and 1897 (Cabral, 2003). These expeditions were aimed for oceanographic exploration but also contributed to a better knowledge on botany and zoology of the Azores, as several of the participant naturalists studied the collected material themselves or sent it to other experts (e.g. Guerne, 1887, 1888; Bolívar, 1892; Barrois, 1896). The Azorean naturalist Afonso Chaves also collaborated in these expeditions.

As a result of these missions Jules de Guerne published the first works on Azorean freshwater fauna, following visits to six of the nine islands (Corvo, Flores, Faial, Pico, Graciosa and São Miguel) (Guerne, 1887, 1888). Moreover, Barrois also published several papers, including the first records of water mites and additions to the fauna of Ostracoda, Cladocera, Branchiopoda, and Rotifera (e.g. Barrois, 1896). A few years later, the physician and naturalist Alfredo Sampaio listed some insects of Terceira and commented on the commonness of the odonates *Aeshna grandis* and *Coenagrion puella* in this island (Sampaio, 1904). However, both species were misidentified by Alfredo Sampaio. According to Cordero-Rivera *et al*. (2005), the former species is clearly referable to *Anax imperator,* whereas the identity of the latter, a zygopteran, remains unclear.

In 1903, during an expedition from 24th February to 29th May 1903, W. Olgivie-Grant collected specially birds in all islands, but also land-shells, and a fair collection of moths, chiefly *Geometridae*, was put together. The Lepidoptera records were published by Warren (1905). After these works, no other checklist of lepidopteran species was issued until 1940, when Rebel's list was published including information from specimens collected by Richard Frey and Ragnar Storå in 8 of 9 islands of the archipelago, following their 1938 expedition (Rebel, 1940).

Two French entomologists, L. Chopard and A. Méquignon, visited the Azores in 1930 (August to September) to collect terrestrial arthropods and several publications ensued from this visit reporting the arthropod diversity found in these islands [e.g. Chopard, 1932 (Orthoptera); Návas, 1933 (Odonata, Neuroptera); Méquignon, 1935, 1942a, b (Coleoptera); Séguy, 1936 (Diptera)]. However, Chopard (1932) considered that the Azorean fauna was despairingly banal; mentioning that observing the insects found he could believe to be just outside Paris.

The first surge in description of new species for the Azores was in the 1940's (Fig. 5) following the mission of R. Frey, R. Storå and C. Cedercreutz who made extensive collections in most islands during 1938, but also as the result of the study of other collections made in the archipelago during the previous decades (e.g. Frey, 1940, 1945, 1948; Rebel, 1940; Lindberg, 1941, 1954; Storå, 1945, 1949; Tiensuu, 1945; Uyttenboogaart, 1947; Uvarov, 1948). Frey was particularly interested in Diptera and he made the first compilation for the archipelago for this group, involving several specialists of different families and including also information for Madeira archipelago which he visited in the same year (Frey, 1945).

The *Queen Mary College Expedition to the isles of Pico and Fayal, Azores*, took place in 1952, from 1st August to 16th September. Among its members was J. D. Carthy, an English entomologist, who collected species of Heteroptera and Lepidoptera. The Heteroptera data from this mission, together with the records of Bernard (1936) and Lindberg (1941, 1954), were included in the list of Azores Heteroptera published by Leston & Carthy (1957). Moreover, Carthy (1957) also published an updated list on Azorean Lepidoptera including data from his own collections.

Swedish professors, Per Brinck and Erik Dahl (University of Lund) organized in 1957 an expedition to the Azores, staying between February and April in these islands (Landin, 1960). Most of the material collected and studied during this visit is in the Zoological Museum of Lund University in Sweden, and the results were published in *Opuscula Entomologica* and in the *Boletim do Museu Municipal do Funchal* (e.g. Freeman, 1959; Dahl, 1960a, b, 1967; Hackman, 1960; Landin, 1960; Lindberg, 1960; Lindroth, 1960; Brinck & Scherer, 1961; Carlsson, 1963; Nielsen, 1963; Denis, 1964; Nybom, 1965; Svensson, 1970, 1977; Brinck ,1977a, b).

The Department of Biology of the University of the Azores organized a total of 15 scientific expeditions in the period 1977-2011, which led to several publications including many on the Lepidoptera of the archipelago (Carneiro, 1982; Carvalho, 1982 1984, 1992; Guimarães, 1982; Sousa, 1982, 1985a, b, 1991, 1999; Meyer, 1991a,b; Vieira & Pintureau, 1991, 1993; Henderickx, 1995; Vieira, 1997, 2003, 2009; Carvalho *et al*., 1999; Tennent & Sousa, 2003; Vieira *et al*., 2003a; Karsholt & Vieira, 2005; Vieira & Karsholt, 2010).

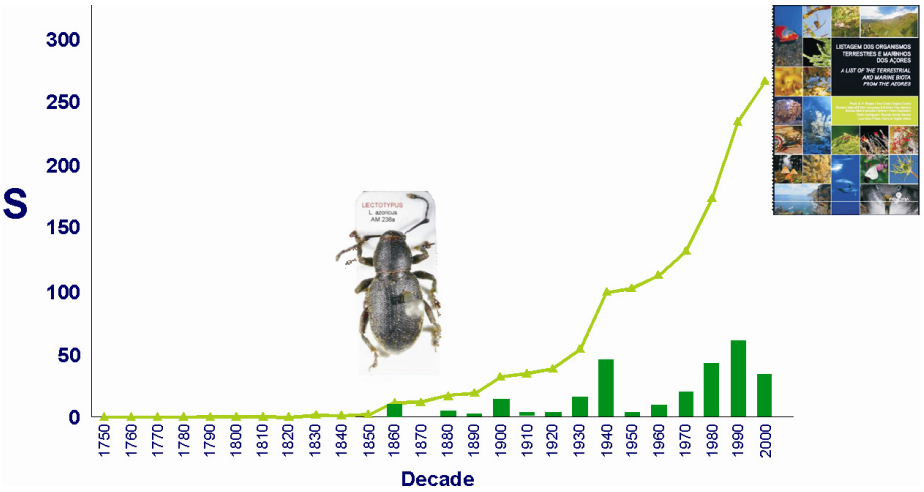


Figure 5. Cumulative discovery curve of the endemic arthropod species and subspecies in the Azores. Data points correspond to the cumulative distribution of the number of endemic taxa (S) based on the decade of their scientific description. Bars represent the number of endemic taxa described in each decade. Data based on Borges *et al*., 2010. The first endemic species described for the Azores *Drouetius azoricus* (Drouët, 1859) is pictured (photo by A. Machado) as well as the book cover of the most recent checklist on Azorean terrestrial arthropods (Borges *et al*., 2010a).

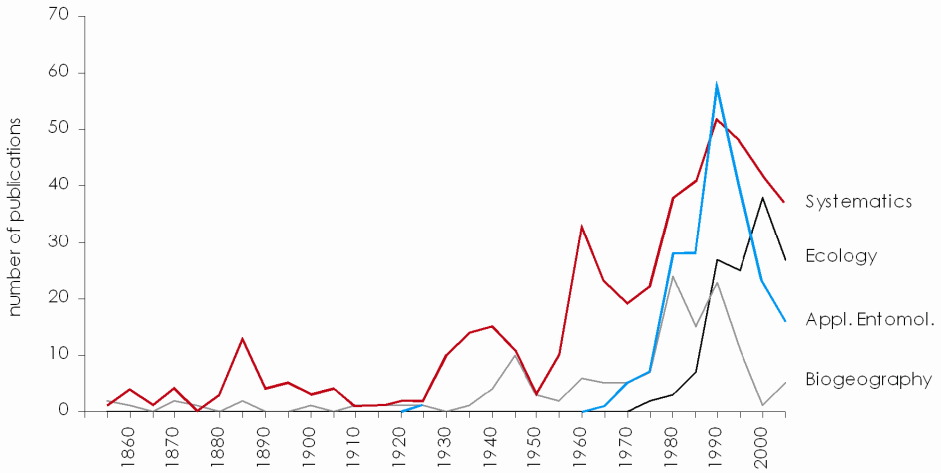


Figure 6. Number of studies published regarding terrestrial arthropods in the Azores archipelago through time, discriminated by subjects: Systematics, Ecology, Applied Entomology and Biogeography (from Gaspar *et al*., 2008).

From 1975 to 1990, some auto-ecological studies were carried out focusing on agricultural pests and on their parasites such as *Mythimna unipuncta* Haworth (Lepidoptera, Noctuidae) (Tavares, 1979; Vieira, 2000; Silva *et al*., 2003; Vieira *et al*., 2003b); *Popillia japonica* Newman (Coleoptera, Scarabaeidae) (Simões & Martins, 1985) and *Trichogramma* sp. (Hymenoptera, Trichogrammatidae) (Oliveira, 1987). But it was only in 1990 that studies on the ecology of arthropod communities started to develop in the archipelago (e.g. Cruz De Boelpaepe, 1991; Braz, 1992; Garcia, 1992; Oliveira & Tavares, 1992; Borges, 1995) (Fig. 6).

The Azorean archipelago was less targeted by entomological scientific expeditions and individual entomologists than Madeira or the Canary Islands. However, recently there has been an increased interest in Azorean fauna and flora. This, together with the establishment of a university in the Azores, made possible the proliferation of a large set of entomological works, which is manifested in the increasing number of publications on the biogeography, ecology, applied entomology, biospeleology and systematics of Azorean arthropods (see Vieira & Borges, 1993; Borges & Vieira, 1994).

Biospeleological work started in the Azores in 1987 and 1989 with the first biospeleological expeditions directed by N.P. Ashmole (Edinburgh University) and P. Oromí (University of La Laguna) supported by the National Geographic Society, USA. As a consequence of these studies a total of 13 troglobitic arthropods endemic to the Azores were described in international and national scientific journals. This effort was continued by P.A.V. Borges and F. Pereira who organized some biospeleological expeditions to several islands resulting in the publication of the first list of Azorean cave fauna in the *Encyclopaedia Biospeleologica* (Borges & Oromí, 2005) and the description of new cave arthropod species (e.g. Borges *et al*., 2007; Borges & Wunderlich, 2008).

An important step in furthering the knowledge on the terrestrial arthropod fauna of the Azores was the implementation of the project *Biodiversity of Arthropods from the Laurisilva of the Azores* (BALA) in 1999. This project allowed the standardized sampling of 7 Azorean islands, the ones that still had native forest (Laurisilva) fragments (see Borges *et al*., 2005a; Ribeiro *et al*., 2005, Gaspar *et al*., 2008). Several national and international experts visited the islands during this project and many others received samples from different taxonomic groups. The project emphasis on inventorying arthropod diversity led to the discovery and description of a considerable number of new species (Fig. 5), and valuable data on species distribution, abundance and ecology was also gathered. Following this project, standardized sampling was also applied to other Azorean islands and habitat types (e.g. exotic forests and pastures) leading to interesting findings (Cardoso *et al*., 2009a, 2010; Meijer *et al*., 2011; Florencio *et al*., 2013).

An important landmark on the knowledge of Azorean biodiversity was the recent publication of two checklists of the fauna and flora of this archipelago (Borges *et al*., 2005b, 2010a). Another essential resource is the "Azorean Biodiversity Portal" (http://www.azoresbioportal.angra.uac.pt/index.php?lang=en). It is a unique means for fundamental research in systematics, biodiversity, conservation management and education. For many species it provides photos and systematic information, and also offers an original platform for biogeographical and macroecological research on islands. For the first time it is possible to have access to the detailed distribution of all Azorean plant and animal species mapped in a 500x500 m grid. This information was based on literature records as well as unpublished data from recent surveys in the archipelago. Together with the distribution data, there is also information on species ecology and conservation, and whenever possible the species is pictured. A more recent update of the database of Azorean biodiversity is now available online: the ATLANTIS database (http://www.atlantis.angra.uac.pt/atlantis/common/index.jsf) that also includes marine biota. The Azorean Regional Government also provides online information on the archipelago biodiversity, including terrestrial arthropods (http://siaram.azores.gov.pt).

Entomological collections containing terrestrial arthropod specimens from the Azores can be found in several institutions across Europe, such as the Natural History Museum in London (UK), the Muséum National d'Histoire Naturelle in Paris (France), the Staatliches Museum für Tierkunde in Dresden (Germany), the Zoological Museum of Lund University (Sweden), the Finnish Museum of Natural History in Helsinki (Finland) and the La Laguna University in Tenerife, Canary Islands (Spain). In Azores there are three important entomological collections: 1) the Dalberto Pombo entomological collection in Universidade dos Açores (Terceira Island) houses many terrestrial arthropod specimens, particularly insects and spiders; 2) the entomological collection pertaining to the project *E.D.E.N. Azorean Habitats* (Environmental Defense of Endangered Natural Azorean Habitats - http://www.eden-azores.com) housed by Universidade dos Açores, in Ponta Delgada (São Miguel); 3) and the entomological collection of Museu Carlos Machado in Ponta Delgada which includes many terrestrial arthropods deposited by Azorean naturalists (e.g. Arruda Furtado, Ernesto do Canto, Carlos Machado, Afonso Chaves), but also as a result of collections made in the archipelago by several international specialists of different groups (see Constância, 1994; Cabral, 2003); the collection has several insect specimens with high scientific and historical value, particularly Coleoptera, Lepidoptera, Odonata and Orthoptera (e.g. Méquignon, 1942b; Vieira & Constância, 2002; Cordero-Rivera *et al*., 2005).

3. The biodiversity of terrestrial arthropods

In the last decade two checklists of terrestrial arthropods of the Azores archipelago were published (Borges *et al*., 2005b, 2010a). These lists were made possible through the collaboration of many taxonomic experts, and resulted from a thorough survey of the literature and also included unpublished information.

The Azores archipelago has 2332 species and subspecies of terrestrial arthropods (Borges *et al*., 2010a, 2013a; Crespo *et al*., 2013, 2014 and unpublished results). Interestingly when we consider the colonization status of Azorean terrestrial arthropods, a great proportion of the taxa existing in the archipelago are introduced (42%) and only 12% are endemic, while for 11% of the taxa there is not enough information to attribute a colonization status (Fig. 7).

São Miguel, the largest and most populated island, is the one with more arthropod species and subspecies (S=1597) followed by Terceira (S=1235), while Corvo only has 263 (Table I; Fig. 8). Comparing the number of introduced species per island, São Miguel and Terceira stand out as the islands with more introduced species (Fig. 8). However, if we consider the proportion of introduced species in each island the values are very similar, ranging between 38% (Corvo) and 47% (Santa Maria and Graciosa).

In Azores the terrestrial arthropod groups (=orders) most rich in taxa are Coleoptera, Diptera and Hemiptera (Fig. 9). This is in general accordance with what happens in terms of diversity worldwide, the exception being Hymenoptera a globally diverse order (comparable with Diptera), but poorly represented in the Azores. However, this difference could be only the reflection that this group has been less studied taxonomically in this archipelago (Borges *et al*., 2005b, 2010a; Lobo & Borges, 2010).

When considering only the endemic species the scenario is a little different of the one obtained for the overall diversity, as in the Azores the orders with more endemic taxa (species and subspecies) are the Coleoptera and Diptera, accounting for 27% and 19% of endemic taxa respectively, followed by Lepidoptera representing 14% of all endemic species, while the Hemiptera account for only 4% (Fig. 10). These findings may result from taxonomic bias; in Azores there are some taxonomic experts on Coleoptera, Araneae and Lepidoptera that have made a great effort during the last decades on the study of specimens from the several islands leading to new findings. However, for other groups, like Diptera and Hymenoptera, no such expertise is available (Lobo & Borges, 2010).

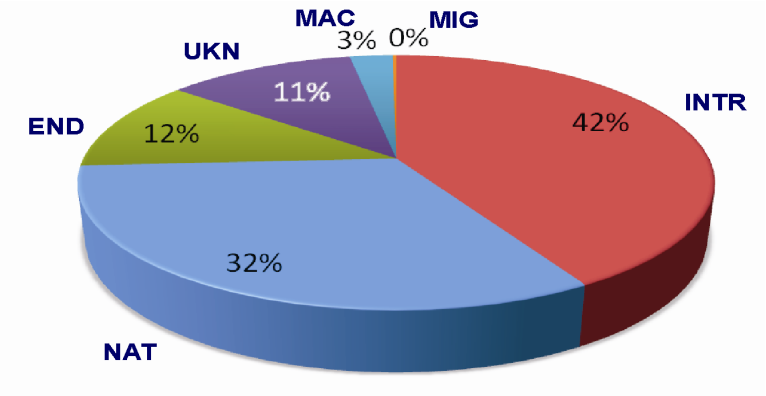
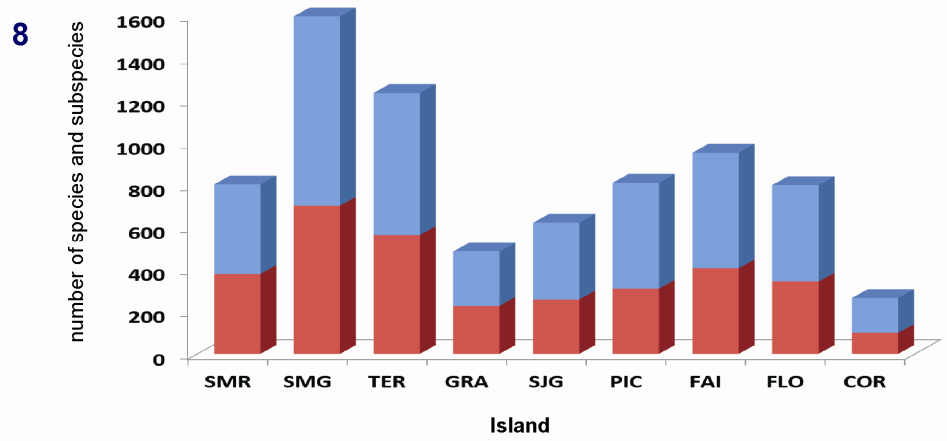


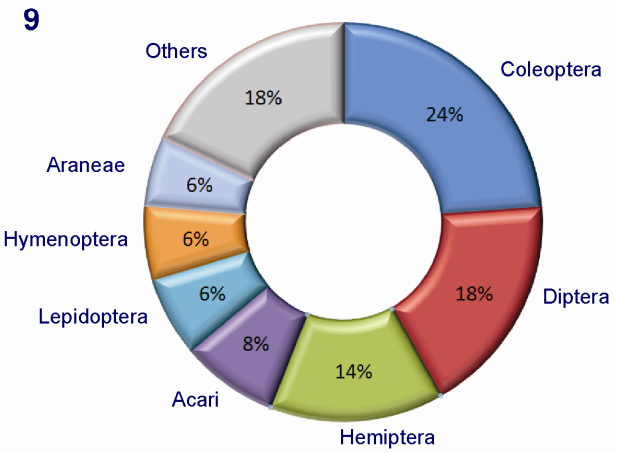
Figure 7. Proportion of species and subspecies according with colonization status. INTR – introduced, NAT – native non endemic, END – endemic, MAC – Macaronesian endemic, MIG- migratory, UKN – unknown.

Table I. Number of terrestrial arthropod taxa from different taxonomic groups in the islands of the Azores and the whole archipelago (Global). The total number of terrestrial arthropod taxa is presented at the bottom. In specific situations, taxa were reported to Azores archipelago without indication of the island where the collection was made (AZ). SMR – Santa Maria, SMG – São Miguel, TER – Terceira, FAI – Faial, PIC – Pico, SJG – São Jorge, GRA – Graciosa, FLO – Flores and COR – Corvo.

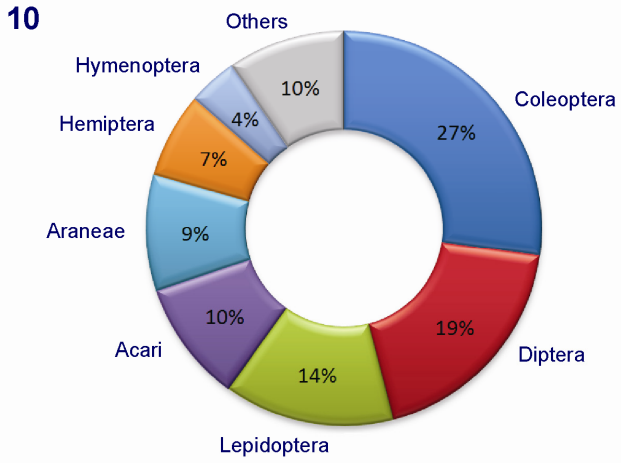
Class/Order	**SMR**	**SMG**	**TER**	**FAI**	**PIC**	**SJG**	**GRA**	**FLO**	**COR**	**AZ**	**Global**
Arachnida	**118**	**202**	**200**	**137**	**121**	**82**	**81**	**96**	**33**	**5**	**327**
Acari: Astigmata	–	10	10	8	4	4	–	4	–	–	16
Acari: Ixodida	2	6	8	1	5	–	–	1	–	1	11
Acari: Mesostigmata	–	15	4	9	5	1	–	2	–	1	24
Acari: Oribatida	36	56	60	33	23	8	21	14	–	3	113
Acari: Prostigmata	–	10	14	8	7	3	–	1	–	–	19
Araneae	76	97	97	73	71	61	55	69	31	–	131
Opiliones	1	3	2	2	2	1	1	2	–	–	3
Pseudoscorpiones	3	5	5	3	4	4	4	3	2	–	10
Malacostraca	**18**	**34**	**19**	**28**	**21**	**2**	**9**	**15**	**3**	**1**	**47**
Maxillopoda	–	–	–	–	–	–	–	–	–	**20**	**20**
Ostracoda	–	–	–	–	–	–	–	–	–	**14**	**14**
Chilopoda	**7**	**11**	**10**	**7**	**8**	**4**	**7**	**5**	**4**	**1**	**14**
Diplopoda	**15**	**21**	**12**	**12**	**11**	**7**	**7**	**12**	**6**	–	**22**
Pauropoda	–	–	–	–	–	–	–	**1**	–	–	**1**
Symphyla	**3**	**1**	**1**	**1**	**2**	–	–	**2**	**1**	–	**3**
Collembola	**20**	**79**	**26**	**34**	**31**	**13**	**6**	**24**	**1**	–	**95**
Diplura	**2**	**1**	**1**	**2**	**1**	**1**	–	–	–	–	**3**
Protura	–	**1**	–	–	–	–	–	**1**	–	–	**2**
Insecta	**620**	**1.247**	**966**	**732**	**616**	**513**	**372**	**644**	**215**	**54**	**1.773**
Blattodea	4	6	4	3	2	2	1	2	1	1	7
Coleoptera	290	355	314	250	188	149	147	200	42	5	556
Dermaptera	3	5	4	4	3	4	4	3	2	–	5
Diptera	40	339	217	181	148	170	59	190	55	12	419
Ephemeroptera	1	1	1	1	1	1	1	–	–	–	1
Hemiptera	112	241	168	104	80	61	54	132	39	21	330
Hymenoptera	17	72	57	38	38	15	9	17	9	11	140
Isoptera	1	2	3	3	–	1	–	–	–	–	4
Lepidoptera	68	112	108	79	96	63	64	66	50	–	151
Microcoryphia	2	2	2	2	4	2	1	1	1	–	4
Neuroptera	4	7	7	6	6	5	3	4	–	–	7
Odonata	4	4	4	4	4	4	2	4	4	–	4
Orthoptera	11	14	8	7	7	2	3	3	4	–	16
Phasmatodea	1	2	1	2	–	–	–	–	–	–	2
Phthiraptera	10	2	–	3	2	–	8	–	–	3	19
Psocoptera	16	33	18	12	9	8	8	8	6	–	36
Siphonaptera	5	12	10	2	1	2	2	5	–	–	15
Strepsiptera	–	–	1	–	–	–	–	–	–	–	1
Thysanoptera	28	32	34	27	22	22	6	5	–	–	49
Trichoptera	–	3	2	3	3	2	–	3	2	1	4
Zygentoma	3	3	3	1	2	–	–	1	–	–	3
Terrestrial Arthropods	**803**	**1.597**	**1.235**	**953**	**811**	**622**	**482**	**800**	**263**	**106**	**2.332**



▲**Figure 8.** Number of species and subspecies per island of the Azores archipelago (in blue) highlighting the number of exotics (in red). SMR – Santa Maria, SMG – São Miguel, TER – Terceira, GRA – Graciosa, SJG – São Jorge, PIC – Pico, FAI – Faial, FLO – Flores and COR – Corvo.



►**Figure 9.** Proportion of species and subspecies of the most taxa rich groups of terrestrial arthropods in the Azores archipelago.



►**Figure 10.** Percentage of endemic species and subspecies of the most speciose groups of terrestrial arthropods in the Azores.

The number of endemic taxa for the Azores is low (less than 300), and the discovery of new species started relatively late (in 1859) (Fig. 5) when compared with other Macaronesian archipelagos (Lobo & Borges, 2010). The fact that the Azores are relatively poor in terms of species is partly explained by the lack of knowledge on the faunistic composition of many insect groups (Borges, 1992; Lobo & Borges, 2010); this particular shortfall has been tackled in the last decades but is still a work in progress. Intrinsic factors such as young geological age, large distance to colonization sources, environmental homogeneity and small archipelago area also play a major role in the low diversity observed in the Azores (Borges & Hortal, 2009; Triantis *et al*., 2012). Further, human disturbance mediated by natural habitat destruction and the introduction of exotic and invasive species has certainly played a role in the impoverishment of island faunas in this archipelago.

The largest island, São Miguel, is the one with more endemic taxa (150), followed by Terceira with 132, while Corvo only has 33 (Fig. 11). In terms of single island endemics (i.e. taxa that occur only in one of the islands) the scenario is a little different with São Miguel having the highest number followed by Santa Maria and Terceira (Fig. 11). Both Corvo and Graciosa have no exclusive endemic taxa; which could reflect the fact that all native forest was destroyed in these islands and as a result their exclusive species are already extinct.

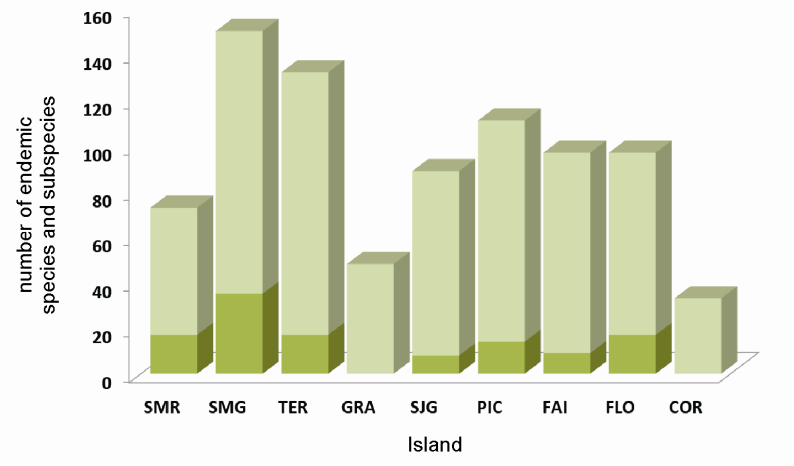


Figure 11. Number of endemic species and subspecies of terrestrial arthropods per island of the Azores archipelago, highlighting (in darker green) the single island endemics: species that occur in only one of the islands. SMR – Santa Maria, SMG – São Miguel, TER – Terceira, GRA – Graciosa, SJG – São Jorge, PIC – Pico, FAI – Faial, FLO – Flores and COR – Corvo.

The Azores present a low number of endemic taxa when compared with other oceanic archipelagos. Further, when we consider the diversification that occurred in these islands, it is also very low as only 18 genera have 3 or more endemic taxa, representing 30% of the overall endemism, while genera with a single endemic species account for 49% (134 species). In this context the Coleoptera represent the group with higher diversification events, including five of the most speciose genera (Fig. 12). The low diversification in Azores is probably due to the recent origin of this archipelago (a large proportion of the island areas is less than 1 My, even in islands with old terrain like São Miguel and Terceira) and its greater isolation from colonization sources, among other factors (e.g. Borges & Hortal, 2009; Triantis *et al*., 2012).

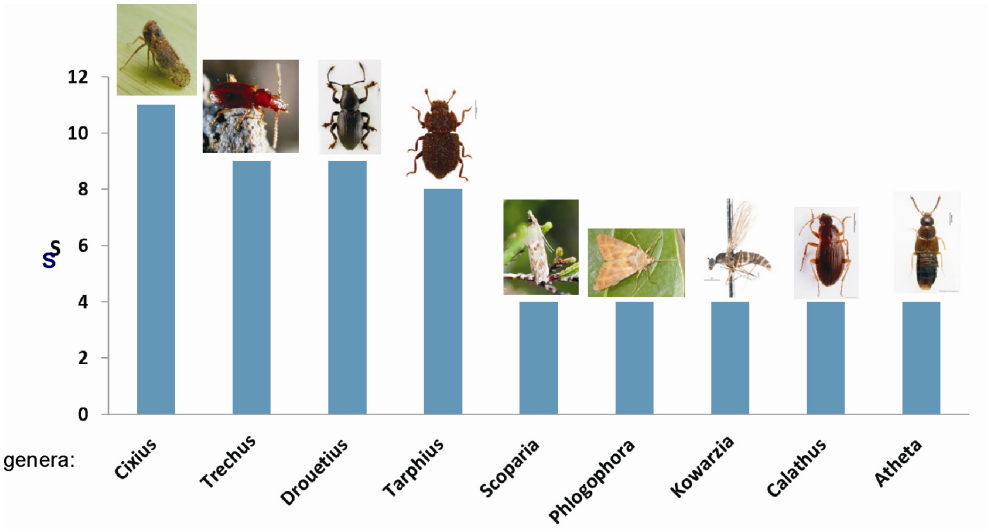


Figure 12. Number of endemic species and subspecies (S) of the most speciose genera of terrestrial arthropods from Azores (Photos by Carla Rego, Paulo A.V. Borges, Javier Torrent, Enésima Mendonça and Virgílio Vieira).

Taxonomic desharmony is a common feature of oceanic islands, i.e. the absence of species belonging to some taxonomic groups that are present in the nearest mainland. It is a result of the different way potential colonizers are affected by the obstacles in reaching islands or the absence of suitable habitats upon arrival. In Azores there are several terrestrial arthropod groups missing, in spite of being common in the nearest mainland. For example the orders Embioptera and Mantodea are completely absent (Borges *et al*., 2010a); further, many families of aquatic insects are also missing and the family Tenebrionidae (Coleoptera) is poorly represented; in addition native spiders are concentrated in a few families (Borges & Wunderlich, 2008).

An assessment of the worst invasive species of Macaronesia was recently published (Silva *et al*., 2008). Several of these species have been reported for the Azores, namely the millipede *Ommatoiulus moreletii*, the woodlice *Armadillidium vulgare* and *Eluma purpurascens*, the spider *Dysdera crocata* and the ants *Paratrechina longicornis* and *Linepithema humile*. However, with the exception of some evaluation of the potential impact of *Dysdera crocata* on Azorean endemic extinct *Dysdera* sp. (Cardoso *et al*., 2010),

Plate I. Endemic species of terrestrial arthropods from the Azores. **a**) *Argyresthia atlanticella*, **b**) *Turinyphia cavernicola*, **c**) *Drouetius borgesi borgesi*, **d**) *Savigniorrhipis acoreensis*, **e**) *Cyclophora azorensis*, **f**) *Trechus terceiranus.* Photos by: a, b, e: Pedro Cardoso; c: Javier Torrent; d, f: Paulo A.V. Borges.

there is still little information on the impacts of these species on native species and ecosystem processes. In urban environments four invasive termite species are known (*Cryptotermes brevis, Kalotermes flavicollis*, *Reticulitermes flavipes* and *R. grassei*) for which there is a bulk of work on their economic impact and biology (e.g. Ferreira *et al*., 2013; Borges *et al*., 2014a; Guerreiro *et al*., 2014).

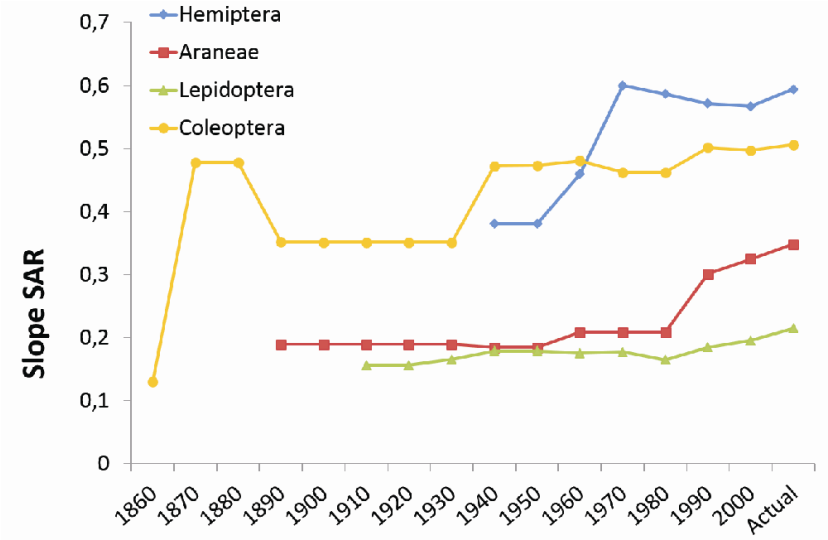


Figure 13. Decadal variation of the slope of the species-area relationship (SAR, using log-log model) for the Azorean Araneae, Hemiptera, Coleoptera and Lepidoptera.

4. Perspectives and challenges for the knowledge and conservation of terrestrial arthropods

The biodiversity of the Azores has been studied for more than one century; however, we still don't know the actual number of species occurring in this archipelago (Borges *et al*., 2010b; Lobo & Borges, 2010). The incomplete knowledge of the taxonomic diversity of a certain area, also called the 'Linnaean' shortfall, is a severe constraint for the understanding and conservation of terrestrial arthropod faunas (Brown & Lomolino, 1998; see also Cardoso *et al*., 2011). The Government of the Canary Islands, aiming to overcome this issue in Macaronesia, coordinated a project on updating the taxonomic knowledge and mapping the biodiversity of the Macaronesian islands (see Izquierdo *et al*., 2001). As a result checklists on the fauna and flora were published for Azores, Madeira, Canary Islands and Cape Verde in the last decade with recent updates for Azores and Canaries (Izquierdo *et al*., 2004; Arechavaleta *et al*., 2005, 2010; Borges *et al.,* 2005b, 2008, 2010a).

The fact that some taxonomic groups have been systematically targeted during the last decades using different techniques and methodologies, together with the easy access to taxonomic experts, leads us to speculate, for instance, that the Azorean fauna of Araneae, Coleoptera and Lepidoptera is quite well known. However, even for these well studied groups new species are still being found in this archipelago (Crespo *et al*., 2013, 2014) and others await description (e.g. *Tarphius* spp. beetles; Borges *et al*., in prep.).

Recently, Lobo & Borges (2010) provided an estimate on the number of terrestrial arthropod taxa of the Azores. These authors, based on the shape of the growth curve of the cumulative number of species as a function of the year of description, showed that current taxonomical knowledge is far from complete. In Azores the number of endemics is below the real species numbers, and additional taxonomic effort is needed to provide a reliable estimation of arthropod biodiversity. This is extremely important in terms of conservation because many Azorean native forest fragments are threatened by invasive species and human activities (Gaspar *et al*., 2011), and unknown species could potentially disappear before being discovered (Talavera *et al*., 2014). Many species (including endemic ones) were only discovered in the last decades, after the implementation of more intense fieldwork, and the use of standardized sampling, as in the case of forest canopies and subterranean habitats (Ribeiro *et al*., 2005; Borges *et al*., 2007; Borges & Wunderlich, 2008). A group of endemic arthropods particularly well studied in the archipelago is the cave adapted species. The twenty terrestrial cave obligate (troglobionts) Azorean endemic arthropod species occur mainly in the islands of Pico, Terceira, São Jorge and São Miguel (Borges & Oromí, 2005; Borges *et al*., 2012).

Another source of potential bias in species inventory for the Azores would be the heterogeneity in the knowledge between islands. Investigating the database ATLANTIS (http://www.atlantis.angra.uac.pt/atlantis/common/index.jsf) we created checklists for Araneae, Hemiptera, Coleoptera and Lepidoptera (four groups that are taxonomically better known) for all the nine islands per decade, and performed species-area curves for each taxon per decade using the log-log model. The result of this exercise is summarized in Fig. 13, and shows clearly that only for Lepidoptera there is a long standing stability in the species inventory between islands. For Coleoptera since 1990 there is some stability in the slope, but for spiders there is no clear stability, which is due to the recent inventory and taxonomic work on this arthropod group (Borges & Wunderlich, 2008; Crespo *et al*., 2013, 2014).

Another source of continuous change in species inventory is the detection of arthropod introductions in islands, a problem that is critical in the Azores. Recently, Borges *et al*. (2013a) listed 23 widespread exotic spider and insect species that were newly recorded from the Azorean Islands in the last few years,

but many other species, including several of the worst invasive, were already known to occur in this archipelago (Silva *et al*., 2008).

Recent advances in molecular and classical systematics allowed the revision of many taxonomic groups, leading to the creation of new synonyms and the description of new species. Consequently, the current list of species is now more stable for some taxonomic groups. However, despite the great knowledge we now possess on the terrestrial arthropod fauna from the Azores, there are still groups where basic knowledge is lacking (Borges *et al*., 2010b; Lobo & Borges, 2010). For instance, the Hymenoptera and Diptera, two of the most species rich insect orders worldwide, are still poorly known. This lacuna is currently being tackled by ecological sampling targeting these groups by the Azorean Biodiversity Group researchers, as well as increased identification efforts. Thus, it is expected that the knowledge on the diversity of these taxonomic groups will increase considerably in the foreseeable future.

The biodiversity of the Azores archipelago faces several threats, among them habitat fragmentation is very important since these islands suffered drastic deforestation since human colonization began in the XV century (Silveira, 2013). Also the intense anthropogenic loss of habitat may have caused an extinction debt for which it is still too early to assess its effects (Triantis *et al*., 2010). A recent palaeoecological study in Flores and Pico Islands demonstrated that there were widespread and persistent vegetation changes during the last 600 years of Human occupation which surpass the impact of Pleistocene climatic changes (Connor *et al*., 2012). One of its consequences was the extinction of several species, now only known by their fossils (Rando *et al*., 2013, unpublished results). Another very important threat is the spread of some invasive plants that are currently occupying large areas of native forest, changing native ecosystems with still unknown impacts in soil ecosystem processes and on native biota.

An important component in nature conservation is increasing public and policymakers awareness for this thematic. Arthropod conservation suffers from several impediments (Cardoso *et al*., 2011) that include a “public dilemma”, i.e. the general public is not aware of invertebrates and their ecological services, as well as a “political dilemma”, i.e. policymakers and stakeholders are mostly unaware of invertebrate conservation problems.

Several recent initiatives have contributed to increase public awareness in terms of Azorean arthropod conservation, being the best example the Azorean Biodiversity Portal (Borges *et al*., 2010c; see section 2 of this chapter) with more than 2000 daily visits. Other relevant webpages led by Azorean experts are:

- Azorean Biodiversity Gallery (http://galeria.azoresbioportal.angra.uac.pt)
- ATLANTIS database (http://www.atlantis.angra.uac.pt/atlantis/common/index.jsf)
- Azorean Spiders (http://www.jorgenlissner.dk/azoreanspiders.aspx)
- Termites from the Azores (http://sostermitas.angra.uac.pt)
- E.D.E.N – Azores Habitats (http://www.eden-azores.com)

The Facebook page “Chama-lhe Nomes” (“Name them”) (https://www.facebook.com/Chama.lhe.Nomes), a project led by Isabel R. Amorim, challenged cybernauts to come up with creative common names for endemic insects, raising awareness for the unique biodiversity of the archipelago. Also the street exhibition “Açorianos há milhões de anos” (“Azoreans for a million years”) led by Isabel R. Amorim, Ana Moura Arroz and Rosalina Gabriel, consisted on 12 large panels with high resolution macrophotos of endemic arthropod species placed on the walls of several buildings in Angra do Heroísmo, a world Heritage City, in order to acquaint Azoreans with their unique Natural Heritage (for more information see http://cita.angra.uac.pt/ficheiros/noticias/1364834635.pdf; Fig. 14).

Another recent example of outreach is the exhibition “*Insetos: vida nos Açores*” ("Insects: wildlife in the Azores") that was developed by Azorean Biodiversity Group members (Clara Gaspar, Carla Rego, Paulo Borges and Pedro Cardoso) and housed in Angra do Heroísmo’s Science Centre "Observatório do Ambiente dos Açores". In the last two years, the exhibition was displayed in most Azorean islands, mostly in Nature Interpretation Centres of local Natural Parks (see http://siaram.azores.gov.pt/centros-interpretacao/intro.html).

The commitment to engage the Azorean people in the invertebrate conservation effort was also addressed through outreach publications. Several books and articles on the biodiversity of Azores or on specific arthropod groups (beetles, spiders and cave arthropods) have been published in the last few years aiming to value and make public the uniqueness of the Azorean Natural Heritage (e.g. Borges & Gabriel, 2009b; Cardoso *et al*., 2009b; Amorim *et al*., 2013, 2015; Borges *et al*., 2013b, 2014b).

All these initiatives contribute to raise public awareness for nature conservation and promote the understanding of why arthropod biodiversity should be valued and protected in the Azores. A great effort has also been made to involve policymakers, such as the Azorean Regional Government and the Azorean Natural Parks, and convincing them to include arthropod species as priorities in conservation planning for the archipelago. As a result, arthropod species that were included in the TOP100 management priority species for the Azores, taking into account both their protection priority and their management feasibility (Martín *et al*., 2008, 2010), were adopted by the Azorean Regional Government in the new law for biodiversity conservation (Decreto Legislativo Regional n.º 15/2012/A, de 2 de Abril).

The TOP100 conservation priority species for the Azores archipelago includes 24 arthropods, 11 of these taxa are also included in the Macaronesia TOP100 (Cardoso *et al*., 2008; Martín *et al*., 2008). Further, 50% of the priority taxa for the Azores are cave dwelling species associated with lava and volcanic tubes. Currently, the Azorean caves that were considered priority for protection, based on the diversity of Azorean arthropod endemic troglobiont species and geo-diversity (Borges *et al*., 2012), are also being considered for inclusion in the biodiversity conservation law (Decreto Legislativo Regional n.º 15/2012/A).

Figure 14. Exhibition "Açorianos há milhões de anos": large outdoor panels in building walls in Angra do Heroísmo depicting high resolution portraits of endemic insects from the Azores (photos by Javier Torrent and Paulo A.V. Borges).

In Portugal, the first protected areas to be established based mostly on information gathered on rare endemic terrestrial arthropods are located in the islands of Terceira and Santa Maria (Borges *et al*., 2011). The Pico Alto protected area, in Santa Maria, was selected based on the presence of unique species and high species richness, i.e. over 57 endemic arthropod species including the endangered *Tarphius pomboi, T. serranoi, T. depressus and T. rufonodulosus*. This protected area harbors the only remaining native forest fragment of Santa Maria (representing <0.25% of the Azorean native forest area) but has an extraordinary level of endemism, i.e. 21% of the Azorean endemic arthropods can be found here. In Terceira, a small fragment of exotic forest that is the single location of *Tarphius relictus* n.sp. (Borges *et al*., in prep.) was also included in Terceira Natural Park aiming to guarantee the survival of this critically endangered endemic.

Thus, the efforts addressed on studying, valuing and making public the Azorean arthropod biodiversity helped to ensure their conservation and are already paying off in terms of local conservation policy. But what can be done at the national and international level to channel resources for arthropod conservation in the archipelago?

The resources allocated for conservation are dictated in part by species conservation assessment. For this we need more detailed information on species distribution, population trends, as well as an understanding of possible conservation threats. For terrestrial arthropods the efforts made in the European Community towards conservation priorities were based on the knowledge on Northern and Central Europe arthropod biodiversity, where a lot more information was available, including historical data. As a result some of the species protected under the Habitats Directive are species that in Portugal are relatively common, while Portuguese endemic species with restricted distributions (like those occurring on islands) received no consideration. The same is not true for the IUCN red lists, where national and international experts collaborated in the elaboration of European red lists for saproxylic beetles, butterflies and dragonflies (Kalkman *et al*., 2010; Nieto & Alexander, 2010; Van Swaay *et al*., 2010).

Five endemic species from the Azores are already included in the IUCN red list (Plate II: two beetles: *Alestrus dolosus* with data deficient status and unknown population trends, and *Crotchiella brachyptera* considered as endangered with unknown population trends; two butterflies: *Hipparchia azorina* (Azores Grayling) and *H. miguelensis* (Le Cerf's Grayling) both considered as least concern but with decreasing

Plate II. Azorean species listed in the IUCN red list. **a**) *Alestrus dolosus*, **b**) *Crotchiella brachyptera*, **c**) *Hipparchia azorina*, **d**) *Hipparchia miguelensis*, **e**) *Ischnura hastata*. Photos by: a, b: Enésima Mendonça; c, e: Pedro Cardoso; d: Virgílio Vieira.

population trends; and one bee: *Hylaeus azorae* considered data deficient as only one male is known from Pico Island (Warncke, 1992; IUCN, 2014).

Non-endemic species are also included in IUCN red lists like *Ischnura hastata*, considered vulnerable with decreasing population trends in the Azores (Kalkman *et al*., 2010). The Azorean populations of this species are extremely important since they are unique being the only parthenogenetic Odonata populations known in the world (Cordero-Rivera *et al*., 2005; Sherratt & Beatty, 2005; Lorenzo-Carballa *et al*., 2009, 2010; Weihrauch, 2011). Other Odonata species that occur in the Azores are also included in the IUCN red list, but they are considered of least concern and with stable population trends (IUCN, 2014).

One important step in raising international awareness for arthropod diversity in the archipelago is the fact that Azorean spiders are presently being evaluated by the recently created IUCN specialist Group - "Spider & Scorpion Specialist Group" - SSSG, and another group will be submitted soon, the IUCN Mid Atlantic Island Specialist Group, in which all the Azorean rare endemic arthropods will be evaluated. This kind of initiatives will promote the international visibility of Azorean endemic arthropods as well as facilitate the creation of guidelines for future biodiversity conservation legislation in the archipelago. This information is also crucial to gather support for national and international financing for arthropod conservation in the Azores.

5. Acknowledgements

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