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New data on the fruit flies (Drosophilidae) of Madeira archipelago with notes on the distribution of the endemic *Drosophila madeirensis* Monclús

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The first findings of drosophilids from Desertas and Porto Santo islands (Madeira archipelago) are reported and the knowledge on the abundance and distribution of the endemic *Drosophila madeirensis* Monclús is updated. This Madeiran endemic was found associated with forest habitats, but was not exclusive of Laurisilva. Furthermore, the finding of widespread populations with moderate abundance indicates that presently this species is not endangered. Finally, we provide an updated checklist of the family Drosophilidae occurring in the Madeira archipelago.

Key words: Desertas islands, endemic species, island biodiversity, Porto Santo island

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The archipelago of Madeira presents a unique natural heritage, which includes a high number of endemic plants and animals (Borges et al. 2008). In the last few years major efforts were addressed to update the knowledge on the taxonomic diversity of Madeira and to identify the most endangered species and the worst invasive ones (Borges et al. 2008; Martín et al. 2008; Silva et al. 2008). This information is extremely helpful to support decision-making in specific nature conservation issues. However, severe knowledge gaps on Madeiran biodiversity were also highlighted as a result of these studies, particularly in what concerns invertebrate species abundance, distribution and ecology (Cardoso et al. 2011).

The drosophilid fauna of Madeira has been the subject of research since the beginning of the last century (Becker 1908; Frey 1939, 1945), with additional contributions made more recently (e.g. Monclús 1984; Rego et al. 2014). In the last decades, three publications have synthesized the knowledge on the taxonomic diversity of Madeira Drosophilidae (Bächli & Báez 2002; Rocha Pité 2002; Bächli 2008), stressing the occurrence of a significant number of species in spite of the scarcity of studies targeting this insect group. In Madeira archipelago, only the drosophilid fauna of the main island has been studied and there is not a single record of this group from Porto Santo and Desertas islands (Bächli 2008). Furthermore,

basic information on the distribution, abundance and ecology of the endemic *Drosophila madeirensis* Monclús is still lacking, as most publications referring to this species have focused mainly on molecular or evolutionary questions (e.g. Papaceit & Prevosti 1989; Khadem et al. 2001, 2012; Rego et al. 2006, 2007a, 2007b; Rego & Boieiro 2010).

The lack of knowledge on species abundance, distribution and vulnerability to disturbance is a serious impediment for an effective conservation of island endemic biodiversity (e.g. Cardoso et al. 2011). For these reasons, data collection on island insect species richness, distribution and abundance is mandatory and will provide valuable information to support decision making in nature conservation management issues. The aim of our study is to report the first findings of drosophilids from Porto Santo and Desertas islands and discuss the distribution and ecology of the endemic *D. madeirensis*. The knowledge on Madeira archipelago Drosophilidae biodiversity is updated and considerations are made on the need to study and protect the insect biodiversity of Madeira.

MATERIAL AND METHODS

The archipelago of Madeira is composed of three groups of islands (Madeira, Desertas and Porto Santo) and is located in the Northeast Atlantic Ocean, 600 km away from the northwestern coast of Africa (Morocco). Madeira Island presents a variety of native habitat-types, including coastal thermophilous vegetation, upland heathland, altitudinal meadows, and the emblematic native laurel forest (Laurisilva). In Desertas and Porto Santo, the landscape is dominated by meadows, where herbaceous species and some interspersed shrubs prevail. In Porto Santo, there are also some patches of cultivated forest (pine and cypress) associated with mountaintops, aiming to minimize the effects of soil erosion. Madeira and Porto Santo are both inhabited, but while in Porto Santo the effects of human activities are notorious and cover the entire island, the complex orography of Madeira and the harsh climate at higher altitudes limited human settlement to lower altitudes, particularly to the southern milder areas.

Insect sampling took place in selected sites from different habitat-types throughout the Madeira archipelago (Table 1).

Table 1. Information on sampling locations and techniques applied. The geographical coordinates (in degrees, minutes and seconds) of each sampling site is indicated together with habitat-type, the altitude (in metres). Site names are listed alphabetically within each island group followed by island group name abbreviation (M-Madeira, D-Desertas, PS-Porto Santo).

Site	Habitat	Lat. (N)	Long. (W)	Alt.	Technique
Calheta (M)	*Eucalyptus* plantation	32°45'6.01"	17°9'14.44"	1004	Pitfall traps
Chão dos Louros (M)	Laurisilva	32°45'36.54"	17°0'50.87"	825	Pitfall traps
Funduras (M)	Laurisilva	32°44'57.88"	16°47'30.23"	593	Pitfall traps
Galhano 1 (M)	Laurisilva	32º48'6.01"	17°10'0.88"	697	Pitfall traps
Galhano 2 (M)	Laurisilva	32º48'1.15"	17º10'14.74"	873	Pitfall traps
Galhano 3 (M)	Laurisilva	32°47'48.30"	17º10'30.04"	952	Pitfall traps
Miradouro das Voltas L (M)	Laurisilva	32°48'27.61"	16°56'59.60"	825	Pitfall traps
Miradouro das Voltas Sn (M)	*Sequoia* plantation	32°48'42.66"	16°57'3.67"	803	Pitfall traps
Miradouro das Voltas Ss (M)	*Sequoia* plantation	32°48'24.01"	16°56'47.18"	832	Pitfall traps
Montado dos Pessegueiros (M)	Laurisilva	32°48'32.40"	17º4'17.29"	462	Pitfall traps
Pico das Pedras L (M)	Laurisilva	32°46'8.22"	16°54'42.12"	1254	Pitfall traps
Pico das Pedras P (M)	*Pseudotsuga* plantation	32°46'32.52"	16°53'47.72"	947	Pitfall traps
Prazeres (M)	Laurisilva	32°46'59.52"	17º11'16.69"	1147	Pitfall traps
Ribeira do Tristão (M)	Laurisilva	32º50'26.70"	17º11'28.39"	717	Pitfall traps
Rosário (M)	*Eucalyptus* plantation	32°45'57.85"	17°1'9.55"	642	Pitfall traps
Santa (M)	Laurisilva	32º50'4.13"	17°10'42.53"	439	Pitfall traps
Doca da Deserta Grande (D)	Coastal	32º31'2.86"	16°30'41.11"	17	Baited traps
Ilhéu do Farol (PS)	Coastal	33°3'13.25"	16°16'43.36"	32	Pitfall traps
Portela (PS)	Urban	33°4'9.73"	16°19'6.96"	192	Baited traps
Vila Baleira (PS)	Urban	33°3'43.60"	16°19'38.03"	26	Baited traps

Different sampling techniques were used to collect the species reported in this study, namely ad-hoc direct sampling, baited traps, and pitfall traps. Baited traps consisted of plastic bottles (6.0 cm diameter and 15.0 cm height) containing fermented banana or beer as bait, with small openings to allow the entry of flies. The baited traps were suspended in trees to avoid disturbance by mice and rats. Pitfall traps were set along a linear transect in various locations (both in forest and open areas) and consisted of plastic cups (4.2 cm diameter and 7.8 cm height) using ethyleneglicol (10%) and a beer-based attractive solution (Turquin 1973) as preservatives.

The specimens collected in this study were sorted and identified in the laboratory and are deposited in the entomological collection of the Departamento de Biologia Animal da Faculdade de Ciências da Universidade de Lisboa (Lisbon, Portugal).

RESULTS AND DISCUSSION

Four drosophilid species - *Drosophila funebris*, *D. phalerata*, *D. repleta* and *D. simulans* - are the first records of Drosophilidae for Porto Santo while *D. repleta, D. simulans* and *Scaptomyza flava* are reported for the first time to Desertas. Comprehensive data on the drosophilid species is presented below. Species are listed alphabetically and follow the phylogeny adopted by Bächli et al. (2004). For each drosophilid species, we present information on site location, sampling date and number and sex of captured specimens. Detailed geographical information of sampling sites and the techniques applied in each location are shown in Table 1.

Drosophila funebris (Fabricius, 1787)
Material examined: SE of Ilhéu do Farol, Porto Santo, 20-6 to 4-7-2011, (1♀).

Drosophila madeirensis Monclús, 1984
Material examined: Santa, 24-5 to 7-6-2011, (11♀); Rosário, 25-5 to 8-6-2011, (3♀); Chão dos Louros, 25-5 to 8-6-2011, (11♀); Ribeira do Tristão, 26-5 to 9-6-2011, (1♀); Calheta, 27-6 to 10-6-2011, (5♀); Prazeres, 28-5 to 11-6-2011, (1♀); Funduras, 31-5 to 14-6-2011, (2♀); Pico das Pedras P, 31-5 to 14-6-2011, (3♀); Pico das Pedras L, 31-5 to 14-6-2011, (4♀); Miradouro das Voltas Ss, 2-6 to 16-6-2011, (3♀); Miradouro das Voltas Sn, 2-6 to 16-6-2011, (14♀); Miradouro das Voltas L, 2-6 to 16-6-2011, (44♀); Galhano 1, 4-7 to 18-7-2012, (2♀); Galhano 2, 4-7 to 18-7-2012, (13♀); Galhano 3, 5-7 to 19-7-2012, (4♀); Montado dos Pessegueiros, 6-7 to 20-7-2012, (1♀). All sites are located in Madeira Island.

Drosophila phalerata Meigen, 1830
Material examined: Vila Baleira, Porto Santo, 24-4 to 26-4-2012, (1♂).

Drosophila repleta Wollaston, 1858
Material examined: Portela, Porto Santo, 22-4 to 26-4-2012, (1♀); Vila Baleira, Porto Santo, 24-4 to 26-4-2012, (1♂); Doca da Deserta Grande, Desertas, 31-7-2012, (18♂, 14♀).

Drosophila simulans Sturtevant, 1919
Material examined: Doca da Deserta Grande, Desertas, 31-7-2012, (10♂, 13♀); Vila Baleira, Porto Santo, 24-4 to 26-4-2012, (7♂, 15♀).

Scaptomyza pallida (Zetterstedt, 1847)
Material examined: Doca da Deserta Grande, Desertas, 31-7-2012, (2♀).

The extensive sampling carried out in Madeira archipelago was important by allowing the first records of drosophilids for Porto Santo and Desertas islands. These findings highlight the poor knowledge on the distribution, abundance and ecology of Madeira drosophilids. Some of the species now reported to Desertas and Porto Santo, like *D. funebris*, *D. repleta* and *D. simulans*, are considered as introductions to the Madeira archipelago (Bächli 2008) and have probably benefited from human-assisted dispersal to spread throughout the archipelago. Madeira archipelago presents an interesting diversity of drosophilids comprising 22 species (Table 2; Rego et al. 2014), which is comparable with other Macaronesian archipelagos: 26 species being known from the Canary Islands (Oromí & Báez 2010) and 20 from the Azores archipelago (Bächli 2010; Borges et al. 2013).

Table 2. Updated list of Madeira archipelago Drosophilidae species. M - Madeira Island, PS - Porto Santo Island and its islets, D - Desertas islands.

Species	M	PS	D
Drosophila busckii Coquilett, 1901	x		
Drosophila funebris (Fabricius, 1787)	x	x	
Drosophila immigrans Sturtevant, 1921	x		
Drosophila phalerata Meigen, 1830	x	x	
Drosophila buzzatii Patterson & Wheeler, 1942	x		
Drosophila hydei Sturtevant, 1921	x		
Drosophila mercatorum Patterson &Wheeler, 1942	x		
Drosophila repleta Wollaston, 1858	x	x	x
Drosophila virilis Sturtevant, 1916	x		
Drosophila ananassae Doleschall, 1858	x		
Drosophila melanogaster Meigen, 1830	x		
Drosophila simulans Sturtevant, 1919	x	x	x
Drosophila madeirensis Monclus, 1984	x		
Drosophila subobscura Collin, 1936	x		
Hirtodrosophila cameraria (Haliday, 1833)	x		
Lordiphosa andalusiaca (Strobl, 1906)	x		
Lordiphosa fenestrarum (Fallen, 1823)	x		
Lordiphosa n. sp.	x		
Scaptodrosophila lebanonensis (Wheeler, 1949)	x		
Scaptomyza pallida (Zetterstedt, 1847)	x		x
Scaptomyza flava (Fallen, 1823)	x		
Scaptomyza graminum (Fallen, 1823)	x		
Zaprionus indianus Gupta, 1970	x		

The drosophilid fauna of Madeira includes one endemic species - *Drosophila madeirensis*. It was was only known from eight localities and believed to be uncommon and strictly associated to laurisilva (Monclús 1984). In this study, however, we found *D. madeirensis* in various laurisilva patches from distant locations in Madeira, and in forest plantations, such as *Eucalyptus*, *Pseudotsuga* and *Sequoia* plantations (Fig. 1). Nevertheless, these findings does not necessarily contradict the association of *D. madeirensis* with laurisilva, as in most cases the forest plantations were in the vicinities of laurisilva patches or had a ground layer of native plants interspersed with the planted trees. On the other hand, *D. madeirensis* is an active flying insect with good dispersal ability being capable to travel within and between forest fragments. In fact, molecular data suggest that this species is represented by a single, only slightly subdivided, population in Madeira, despite the complex orography of this island (Lepetit et al. 2002). Furthermore, our findings considerably increase the knowledge on the spatial distribution of this species and several historical records were confirmed (Fig. 1). D. madeirensis was recorded in low to moderate abundance and has never been reported from non-forest habitats suggesting a preference for more humid and shaded environments. In fact, experimental studies with laboratorial populations, have shown that *D. madeirensis* prefers lower temperatures and is less tolerant to heat desiccation than its closest relative, the widespread *D. subobscura* (Rego & Boieiro 2010).

At present, there is some evidence that *D. madeirensis* may be susceptible to habitat disturbance and to the presence of exotic drosophilids (Rego et al. 2014). Although this endemic does not seem in peril, the recent introduction and fast spread of two invasive drosophilids in Madeira may have unpredictable consequences on its abundance and distribution (Rego et al. in prep).

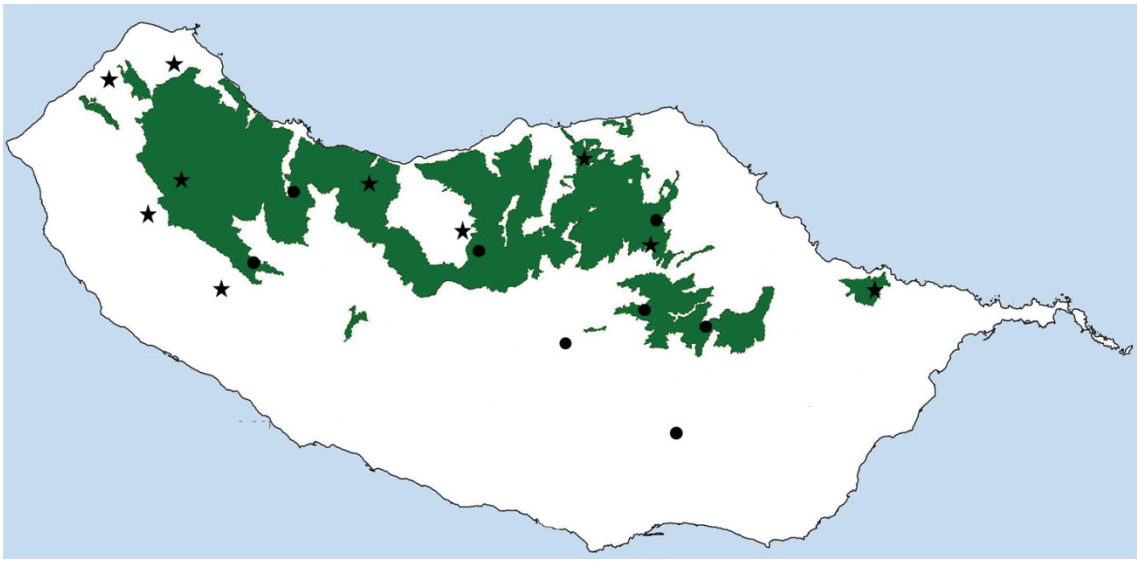

Fig. 1. Distribution of *Drosophila madeirensis* in Madeira Island. Circles represent previously known locations from Monclús (1984) and stars are new locations from the present study. Laurisilva cover is shown in green.

Taking in consideration the rich insect biodiversity of Madeira archipelago, the high levels of endemism and the low biotic resistance of many island species, major conservation efforts should be implemented to improve the knowledge on species taxonomy, abundance, distribution and ecology to support decision-making based on sound science. Furthermore, species and spatial conservation priorities should be identified for different insect groups for the Madeira archipelago and specific legislation must be outlined to safeguard these species and their habitats. On the other hand, the development of habitat and species monitoring programs will be very helpful to assess changes in the conservation status of native species as well as for the early detection of invasive species that may impact native diversity. Finally, a nature conservation strategy targeting the insect biodiversity of Madeira archipelago and valuing collaborative work and communication between scientists, decision-makers and the general public, must be designed and implemented in the short term if we aim to stop biodiversity loss in oceanic islands.

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