Ann. Limnol. - Int. J. Lim. 45 (2009) 59–67
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DOI: 10.1051/limn/2009012

Available online at:
www.limnology-journal.org

Chironomidae (Diptera: Insecta) in oceanic islands: New records for the Azores and biogeographic notes

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Received 28 March 2009; Accepted 20 April 2009

Abstract – Oceanic islands freshwater systems are unique due to their volcanic origin, oceanic situation, catchment morphology and the presence of distinct freshwater communities when compared with continental systems. This study provides an update of Azorean chironomid fauna records, distribution data and includes biogeographical comments, based on collections covering a range of freshwater habitats on several islands over 2005 to 2008. Island species area-relationships or ISAR was performed as a descriptive model for species accumulation patterns in each island in relation to their area. Six new chironimid species records are given for the Azores archipelago: **Orthocladiinae:** *Orthocladius* (*Eudactylocladius*) *fuscimanus* (Kieffer, 1908), *Pseudorthocladius* (*Pseudorthocladius*) *curtistylus* (Goetghebuer, 1921), *Synorthocladius semivirens* (Kieffer, 1909), *Parachaetocladius abnobaeus* (Wülker, 1959); **Chironominae:** *Chironomus* (*Chironomus*) *annularis* (Meigen, 1818), *Parachironomus tenuicaudatus* (Malloch, 1915). As a result, the Azorean chironomid fauna has increased from 38 to 44 species, spread across 33 genera. Most recorded chironomids are primarily of western Palaearctic origin; Nearctic, Oriental and Neotropical regions are comparatively poorly represented. A check-list is provided, incorporating and updating previous records. Chirononidae distribution pattern among the islands is analyzed and island species area-relationship (ISAR) analyses, performed to provide a descriptive model for species accumulation patterns in each island, indicated a positive correlation between species richness (number of species) and the area of the Azorean islands, supporting MacArthur and Wilson's equilibrium theory of island biogeography. Chironomidae could be promising for searching candidate bioindicators to answer the demand of Water Frame Directive.

Key words: Island species-area relationship (ISAR) / Insecta / Chironomidae / Azores / oceanic islands / distribution

Introduction

The Chironomidae comprise a widely distributed group of insects with an aquatic larval stage that often occurs high densities and diversity in freshwater and marine environments (Pinder, 1986; Ashe *et al.*, 1987; Armitage *et al.*, 1995; Osborne *et al.*, 2000). The diversity of chironomid species is exceptionally high with an estimated worldwide number of 15 000 species (Cranston and Pinder, 1995).

The occurrence of freshwater insects in oceanic islands has always raised interest concerning mechanisms of dispersal, colonization and evolution and even their absence is used as evidence concerning mechanisms that govern those processes (Bilton *et al.*, 2001; Cowie and Brenden, 2006). Owing to their isolation and lack of contact with continental landmasses, oceanic islands are natural laboratories for the study of patterns and processes of dispersal, colonization and speciation and the testing of ecological, evolutionary and biogeographical theories such as the dynamic equilibrium model of island biogeography (MacArthur and Wilson, 1967) and more recently the general dynamic theory of oceanic island biogeography (Triantis *et al.*, 2008; Whittaker *et al.*, 2008; Borges and Hortal, 2009).

The Azores are part of the Macaronesian faunal subregion that also includes Madeira, the Canaries and the Cape Verde Islands. They are the most remote

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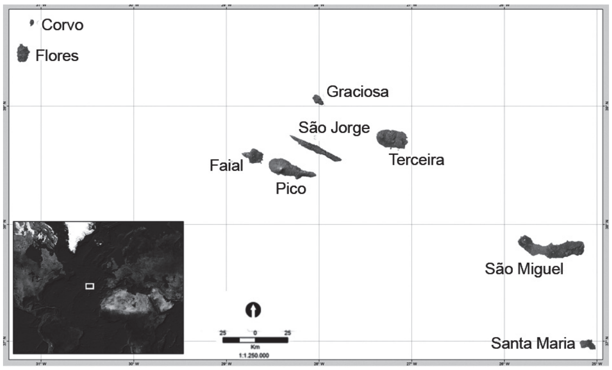

Fig. 1. The Azores archipelago.

archipelago in the North Atlantic (Fig. 1), situated 1300 km from the European mainland and 1900 km from the American continent, and constitute an ideal system to test biogeographical hypothesis. As is typical of island ecosystems, the insect fauna of the Azores is depauperated in comparison to continental systems, due to the islands' volcanic origin, extreme isolation, small size, geological youth and the torrential character of freshwater environments (Borges and Brown, 1999). These strong environmental filters limit the range of freshwater organisms able to colonize island stream systems. The Azorean freshwater fauna is dominated by insect orders, in particular the Diptera. However, some taxonomic groups are absent (*e.g.* Plecoptera) or represented by orders containing only a single species (*e.g.* Ephemeroptera – *Cloeon dipterum*) or families containing few genera (*e.g.* Hydroptilidae – *Hydroptila fortunate, H. vectis, Oxyethira falcate*) or even a single species (*e.g.* Limnephilidae – *Limnephilus atlanticus*). The most diverse Azorean dipteran family is Chironomidae (Borges *et al.*, 2005).

The Azorean chironomid fauna has been studied by several workers during the last century. Frey (1944) and Stora (1945) reported on Azorean Chironomidae, while Freeman (1959) provided additional records from collections made by Brinck and Dahl from the Lund University Expedition to Azores and Madeira in 1957. Cobo *et al.* (2002) applied current taxonomy to the Azorean records compiled by Kehlmaier (1998). More recent records of Chironomidae were provided by Murray *et al.* (2004) from collections made during the summer of 1997 and the autumn of 1998. Murray *et al.* (2004) in their review of Chironomidae from the Azores gave a total of 49 species, including species regarded as *nomen dubium* and genus level identification. By excluding the genus level and *nomen dubium* Murray *et al.* (2004) recorded 38 species for the Azores archipelago, the same number of species that Diaz *et al.* (2005) gave in their compiled list. The number of species known from each island varies from 5 in Corvo to 30 in São Miguel.

This study provides an update of Azorean chironomid fauna records, distribution data and includes biogeographical comments, based on collections covering a range of freshwater habitats on several islands over 2005 to 2008. Island species area-relationships or ISAR was performed as a descriptive model for species accumulation patterns in each island in relation to their area.

Methods

Area of study: The Azores

The archipelago of the Azores (latitude: 36°55'-39°43'N (530 km); longitude: 25°00'-31°17'W (320 km)), comprises nine islands and several islets, astride the Mid Atlantic Ridge. São Miguel and Corvo are the largest and smallest islands with 745 km^2 and 17 km^2, respectively. Santa Maria is the Southern and Easternmost Island (37° N, 25° W). The nine islands form three groups (Fig. 1) separated by 1000 to 2000 m deep sea channels. The Azorean climate is oceanic and temperate with mean annual temperatures of 14–18 °C and mean annual precipitation of 740–2400 mm (Bettencourt, 1979). Wind patterns differ among groups of islands with South and Southwest prevailing winds in Western and Central groups, whereas in Eastern group winds predominate from North and Northeast directions. Strongest winds blow from South and West largely surpassing the wind average speed of 16.8 $km.h^{-1}$ (Porteiro, 2000).

Geologically, the Azores comprise a 20–36 Myr old volcanic plateau; the oldest rocks emerged 8.12 Myr ago (Santa Maria island) while the youngest (Pico island) is about 0.250 Myr old (Borges and Brown, 1999; Quartau, 2007). Recurrent volcanic activity in the archipelago may have promoted extinction, fragmentation, (re)colonization, and allopatric speciation events (Cook, 1996). Geologically these islands are the youngest of Macaronesia (biogeographical region that comprehends the archipelago of Azores, Madeira, Canary Islands and Cape Verde).

Lotic systems are characterized by small (most less than 10 km^2), short and steep watersheds (Smith *et al.*, 2003; Hughes, 2005; Hughes and Malmqvist, 2005) with short, steep, deeply incised streams. Permanent streams, fed by lakes or spring waters, exist only in Santa Maria, São Miguel, São Jorge, Faial and Flores islands (DROTRH/INAG, 2001). The Azores is particularly rich in lentic habitats, with over 88 lakes (see Porteiro, 2000), that occupy 0.4% of the regional territory located in São Miguel, Terceira, Pico, Flores and Corvo. Lentic systems tend to be flooded volcanic craters, caldeiras and *maars* (shallow but broad craters formed by explosive excavation into older lithologies during phreatomagmatic eruptions (Azevedo, 1998; Nunes, 1999)).

Data analysis

Collections were made at 69 sites, covering several types of freshwater habitat in seven of the nine islands of the Azorean archipelago (site locations, dates and collection made are given in Table 1). Field programmes were carried out in 2006 (17 sites), 2007 (24 sites) and 2008 (27 sites). Qualitative samples were collected by scooping floating debris with a hand net (mesh size: 250 μm) along the surface waters of ponds, lakes, streams, reservoirs and animal drinking troughs (Ferrington *et al.*, 1991; Wilson, 1996; Wilson and Ruse, 2005). Samples were collected using drift-nets with 250 μm were used in some streams (Hardwick *et al.*, 1995; Wong *et al.*, 2004). After collection, samples were readily sieved (mesh size: 250 μm) and preserved in 70% ethanol. Material was sorted and identified in the laboratory using keys by Langton (1991), Langton and Visser (2003) and Bouchard and Ferrington Jr. (2008).

Island species area-relationships or ISAR were analyzed utilizing the power function (Whittaker and Fernandez-Palacios, 2007) as a descriptive model for species accumulation patterns, described by $S = cA^z$, expressed as a log-log model: $\log_{10} Y = c + z\log_{10} X$, where X is the explanatory variable number of units of area (A), and Y is the response variable species richness (S). The intercept (c) is the expected number of species in a unit area and Z is the rate of increase of species with area.

The confidence interval for the regression gives the range of variable values computed for the region containing the true relationship between the dependent and independent variables, for the specified level of confidence was calculated by SPSS 15.0.

Results

A total of 32 Chironomidae species, distributed among 24 genera, 3 subfamilies and 5 tribes, were collected as a result of this study (Table 2, available at www.limnology-journal.org). The Orthocladiinae (16 taxa) showed the greatest richness, followed by Chironominae (12 taxa) and Tanypodinae (4 taxa). Far more species were exclusive to lotic systems (52%) than lentic systems (16%), while 32% were found in both systems.

There were new records for seven islands, *i.e.* some of the newly recorded species had already been recorded from other islands in the archipelago: 4 species for Corvo, 8 species for Flores, 8 species for Faial, 7 species for Pico, 5 species for São Jorge, 10 species for São Miguel and 16 species for Santa Maria (Table 3, available at www.limnology-journal.org).

Six species comprised new records for the Azores archipelago; the following section provides brief notes on the records with information on their wider distribution patterns.

Orthocladiinae

The Orthocladiinae occupies the widest range of habitats of all chironomids (Oliver, 1971; Oliver and Dillon, 1997) and is described primarily as a cold-adapted subfamily, although orthoclads also occur in many warm habitats. Larvae occur in all types of running and standing waters.

Orthocladius (*Eudactylocladius*) *fuscimanus* (Kieffer, 1908)

Orthocladius (*Eudactylocladius*) sp. was previously collected by Murray *et al.* (2004) from São Miguel, Terceira and Flores. Exuviae of this species were collected from sites on Santa Maria, São Miguel, Pico, Faial and Flores. This species was one of the most abundantly occurring taxa at stream sample sites. It has a circum-Mediterranean distribution (Langton and Visser, 2003) and also occurs on the Canary Islands (Baez and Armitage, 1990) and Madeira (Hughes, 2008).

Pseudorthocladius (*Pseudorthocladius*) *curtistylus* (Goetghebuer, 1921)

Exuviae of this Holartic species (Langton and Visser, 2003) were collected from Ribeira do Grande e Ribeira Cachaço on Santa Maria. Murray *et al.* (2004) recorded a single *Pseudorthocladius* adult male collected over rocks on the marine shoreline at Ponta Delgada (São Miguel). The species was reported from Madeira by Hughes and Murray (2000), is also occurs on the Canary Islands (Oromí and Báez, 2001).

Parachaetocladius abnobaeus (Wülker, 1959)

A new generic record for the Azores. The characteristic pupal exuviae of the species were collected from streams in Flores and São Miguel. The species is present in continental Europe but Holartic in origin (Langton and Visser, 2003).

Synorthocladius semivirens (Kieffer, 1909)

A new record for this monospecific genus. Exuviae were collected in abundance from streams in Faial, Flores and São Miguel. According to Saether and Spies (2004) it is a Palaearctic species, present in Madeira (Hughes, 2008).

Chironominae

Most species of Chironominae are essentially warm-adapted and live in standing water, though they are not uncommon in cool habitats and in running waters (Oliver and Dillon, 1997).

Chironomus (*Chironomus*) *annularius* (Meigen, 1818)

The first record of this species for Macaronesia. This species was collected from lakes of Flores and São Miguel, and water troughs in Flores, São Jorge and Pico; it is abundant in enriched lentic systems. Exuviae of *C. riparius* were obtained together with a second species tentatively identified as *C. cf annularius* (Murray *et al.*, 2004) from an artificial pool at Santa Cruz Community Centre (Flores). *C. annularius* is an Holartic species, widespread in Europe (Langton and Visser, 2003).

Table 1. Sites location, dates and codes of collections.

Date	Code	Location	UTM	
		Santa Maria		
22-02-2008	RGC (a)	Ribeira Grande e Cachaço, near the mid region	674049	4091110
26-05-2008	RGC (b)	Ribeira Grande e Cachaço, near the mid region	674049	4091110
22-02-2008	RSA (a)	Ribeira Santo Amaro, near the mid region	671903	4095213
26-05-2008	RSA (b)	Ribeira Santo Amaro, near the mid region	671903	4095213
22-02-2008	STMRS (a)	Ribeira do Salto, near the mid region	673503	4094710
26-05-2008	STMRS (b)	Ribeira do Salto, near the mid region	673503	4094710
22-02-2008	RSF2 (a)	Ribeira de São Francisco, near the mid region	667426	4092327
26-05-2008	RSF2 (b)	Ribeira de São Francisco, near the mid region	667426	4092327
		São Miguel		
25-05-2006	RTX	Ribeira Teixeira, near the source	632566	4183324
25-05-2006	RTX2	Ribeira Teixeira, near the mid region	632183	4183864
02-06-2006	EM1	Lagoa Empadas Norte, shore line	610283	4187064
02-06-2006	EM2	Lagoa Empadas Sul, shore line	610171	4187217
16-06-2006	CGM	Lagoa Congro, shore line	640305	4179965
16-06-2006	BRM	Lagoa São Brás, shore line	640006	4184047
21-09-2006	VM1	Lagoa Verde, shore line	606507	4189204
21-09-2006	AZ1	Lagoa Azul, shore line	607466	4192044
11-02-2008	AFG1	Afluente Lagoa Fogo 1	633135	4181016
11-02-2008	AFG2	Afluente Lagoa Fogo 2	635340	4179968
11-02-2008	RP0	Ribeira da Praia	634926	4178177
14-02-2008	FA1	Furnas North affluent	646828	4181206
26-02-2008	RG1	Ribeira Grande, near the source	635727	4182125
26-02-2008	RG2	Ribeira Grande, near the mid region	632678	4184241
26-02-2008	RG3	Ribeira Grande, near the mouth	630370	4187057
26-02-2008	RQ2	Ribeira Quente, near the mid region	649969	4177833
26-02-2008	RQ4	Ribeira Quente, near the mouth	650054	4182022
29-02-2008	RFT0	Ribeira do Faial da Terra, near the source	658386	4183727
29-02-2008	RFT1	Ribeira do Faial da Terra, near the mid region	659741	4182513
29-02-2008	RFT2	Ribeira do Faial da Terra, near the mouth	658167	4178924
29-02-2008	RPV4	Ribeira da Povoação, near the mouth	654914	4179591
02-03-2008	RC2	Ribeira dos Caldeirões, near the mid region	651890	4190772
04-03-2008	RGU0	Ribeira do Guilherme, near the source	657993	4184675
04-03-2008	RGU1	Ribeira do Guilherme, near the mid region	660644	4186220
		Faial		
06-05-2006	RFL (a)	Ribeira dos Flamengos, near the mid region	356085	4268390
28-05-2008	RFL (b)	Ribeira dos Flamengos, near the mid region	356085	4268390
17-09-2008	RFL (c)	Ribeira dos Flamengos, near the mid region	356085	4268390
		Corvo		
10-02-2008	CLA1	Caldeirões Northwest affluent	661886	4397293
		Flores		
10-02-2006	FNM	Lagoa Funda	653464	4363323
27-07-2006	RSM	Lagoa Rasa	652597	4364125
20-07-2007	RB0	Ribeira da Badanela, near the source	653940	4370640
21-07-2007	RB1	Ribeira da Badanela, near the source	654059	4370617
21-07-2007	RB2	Ribeira da Badanela, near the mouth	659659	4370615
22-07-2007	RGR0	Ribeira Grande, near the source	654071	4366606
22-07-2007	RGR1	Ribeira do Ferreiro, near the source	652094	4368148
22-07-2007	RGR2	Ribeira Grande, near the mid region	651031	4366625
22-07-2007	RGR3	Ribeira Grande, near the mouth	649807	4366937
23-07-2007	FLC1	Trough	654930	4361352
23-07-2007	FLC2	Trough	655891	4360746
23-07-2007	FLC3	Trough	655334	4361178
23-07-2007	FLC4	Trough	655916	4360758
23-07-2007	FLC5	Trough	653375	4361490
23-07-2007	FLC6	Trough	652528	4361874
23-07-2007	FLC7	Trough	653033	4361975
23-07-2007	FLC8	Trough	655097	4364641
23-07-2007	FLC9	Trough	655778	4363941

Table 1. (Continued).

Date	Code	Location	UTM	
23-07-2007	FLC10	Trough	657103	4366011
23-07-2007	FLC11	Trough	657654	4366185
23-07-2007	FLC12	Trough	658016	4366144
23-07-2007	FLC13	Trough	660332	4367755
		Pico		
05-05-2006	ROS	Lagoa Rosada	396412	4254546
05-05-2006	CAI	Lagoa do Capitão	384894	4260829
05-05-2006	PAU	Lagoa do Paúl	392334	4254113
07-08-2007	PIC 2	Pico 2	373551	4261978
07-08-2007	PIC 3	Pico 3	392085	4256181
		São Jorge		
14-08-2006	Jor 2	Trough	390280	4288157
14-08-2006	Jor 3	Trough	399622	4282255
14-08-2006	Jor 7	Trough	414107	4276467
13-08-2007	JR-SJOR1	Trough	427667	4267081
13-08-2007	JR-SJOR2	Trough	395147	4283713
13-08-2007	JR-SJOR3	Trough	390999	4286387

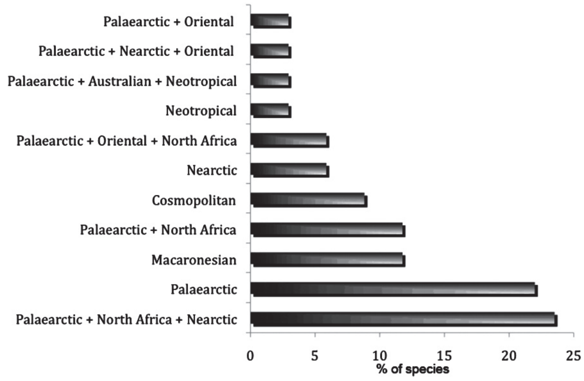

Fig. 2. Biogeographic origin of Azorean chironomids. Percentages of each origin are shown.

Parachironomus tenuicaudatus (Malloch, 1915)

The first record of this species for the Macaronesia. *P. tenuicaudatus* was found in Ribeira da Praia in São Miguel and is now the first generic record for the Azores. According to Langton and Visser (2003) it is an Holartic species characteristic of lakes.

Biogeographic origin – break down

The Azorean chironomid fauna is predominantly Western Palaearctic in origin (see Fig. 2) with most taxa originating from Europe. Nearctic and North African taxa are less well represented. A smaller number of taxa occurs across several biogeographical regions. For example *Chironomus riparius* (Meigen, 1804) and *Cricotopus* (*Isocladius*) *sylvestris* (Fabricius, 1794) have a worldwide distribution, while *Smittia aterrima* (Meigen, 1818) is found in Palaearctic, Nearctic and Oriental regions. *Thalassomya frauenfeldi* (Schiner, 1856) is a Neotropical species.

Macaronesian species constitute 12% of the chironomid Azorean fauna. *Cardiocladius freyi* (Stora in Frey, 1936) and *Thalassosmittia atlantica* (Stora in Frey, 1936) occur in the Azores, Madeira and Canary Islands. *Diamesa alata* (Stora, 1945) and *Microsepta freyi* (Stora, 1945) are known from the Azores and Madeira. No Azorean endemic species are yet described.

Species-area distributions

A positive correlation ($r = 0.88$, $n = 9$, $P = 0.002$) was evident between species richness (number of species) and island area (Table 3). The relationship between island area A and species number S for the nine islands was best described by a power function equation ISAR (1):

$$\mathrm{Log}(S) = 0.5135 + 0.3597 * \log(A). \qquad (1)$$

Flores was a clear outlier in this relationship (outside the 99% confidence interval), exhibiting higher than expected species richness in relation to its surface area (Fig. 3).

Discussion

Based on species level identifications only (*i.e.* excluding *nomen dubium* and genus level identification), this study increases the number of species occurring in the Azores from 38 to 44 (Table 4), distributed across 33 genera and five subfamilies Telmatogetoninae, Tanypodidae, Orthocladiinae, Diamesinae and Chironominae (Fig. 4). The number of recorded species for each island is now 40 for São Miguel (an increase of 25%), 29 for Terceira, 28 for Flores (an increase of 28%), 22 for São Jorge (an increase of 22%), 18 for Faial (an increase of 33%), 20 for Pico (an increase of 35%), 14 for Santa Maria (an increase of 89%) and 9 for Corvo (an increase of 44%). The total number of chironomid species is still lower than in the other Macaronesian archipelagos; Madeira has 60 species (Hughes, 2008), while the Canary Islands has 58 (Baez and Garcia, 2001).

Table 4. Updated list of chironomid for the Azores archipelago.

	COR	FLO	FAI	PIC	GRA	SJG	TER	SMG	SMR
Chironominae									
Chironomus (*Chironomus*) *annularius* (Meigen, 1818)				N Isl		N Az		N Az	
Chironomus cingulatus (Meigen, 1818)		N Isl	N Isl		P	N Isl	P	C	
Chironomus dorsalis (Meigen, 1818)		C	P	N Isl		P	P	C	
Chironomus riparius (Meigen, 1804)		C	P	P	P		P	C	N Isl
Chironomus venustus (Staeger, 1839)					P	P	P	P	
Glyptotendipes barbipes (Staeger, 1839)					P		P	C	
Glyptotendipes pallens (Meigen, 1804)					P		P	N Isl	
Micropsectra junci (Meigen, 1818)	P	P	P	C		C	P	C	
Micropsectra lindrothi (Goetghebuer, 1931)		C						N Isl	
Parachironomus tenuicaudatus (Malloch, 1915)								N Az	
Paratanytarsus grimmii (Schneider, 1885)		N Isl	N Isl				P	N Isl	N Isl
Polypedilum nubeculosum (Meigen, 1818)			N Isl	P			P	C	
Polypedilum nubifer (Skuse, 1889)					P		P	N Isl	N Isl
Diamesinae									
Diamesa alata (Stora, 1945)			P				P	P	
Orthocladiinae									
Camptocladius stercorarius (De Geer, 1776)	N Isl	C	P	P		P	P	C	N Isl
Cardiocladius freyi (Stora in Frey, 1936)		C				P	P	C	N Isl
Chaetocladius melaleucus (Meigen, 1818)	C	C	N Isl				P	C	
Cricotopus (*Isocladius*) *ornatus* (Meigen, 1818)				N Isl			P	C	N Isl
Cricotopus (*Isocladius*) *sylvestris* (Fabricius, 1794)					P	N Isl	P	C	N Isl
Eukiefferiella gracei (Edwards, 1929)		P	P	P		P		P	
Halocladius varians (Staeger, 1839)		P	P	P	P	P		P	
Limnophyes minimus (Meigen, 1818)		C	P	P		P	P	C	N Isl
Metriocnemus carmencitabertarum (Langton and Cobo, 1997)							P		
Metriocnemus fuscipes (Meigen, 1818)		P	P	P		P	P	P	
Orthocladius (*Eudactylocladius*) *fuscimanus* (Kieffer, 1908)		N Az	N Az	N Az				N Az	N Az
Parachaetocladius abnobaeus (Wülker 1959)		N Az						N Az	
Parametriocnemus stylatus (Kieffer, 1924)		C	P				P	C	N Isl
Psectrocladius limbatellus (Holmgren, 1869)	N Isl	N Isl		N Isl		N Isl		C	
Psectrocladius sordidellus (Zetterstedt, 1838)	P	C	C	N Isl		P	P	C	
Pseudorthocladius (*Pseudorthocladius*) *curtistylus* (Goetghebuer, 1921)									N Az
Pseudosmittia brevifurcata (Edwards, 1932)				P	P	P			
Rheocricotopus atripes (Kieffer, 1913)		C	C			C	P	C	N Isl
Synorthocladius semivirens (Kieffer, 1909)		N Az	N Az					N Az	
Smittia aterrima (Meigen, 1818)								P	
Smittia contingens (Walker, 1956)								P	
Thalassosmittia atlantica (Stora in Frey, 1936)	P	P	P	P	P		P	P	
Thienemannia gracei (Edwards, 1929)						P			P
Thienemanniella clavicornis (Kieffer, 1911)	N Isl	C					P	C	N Isl
Tanypodinae									
Macropelopia nebulosa (Meigen, 1804)		P	P			P	P	P	
Paramerina cingulata (Walker, 1856)	N Isl	N Isl	N Isl			N Isl	P	C	N Isl
Procladius choreus (Meigen, 1804)		N Isl		N Isl	P		P	N Isl	N Isl
Telmatopelopia nemorum (Goetghebuer, 1921)		C	N Isl	C		C	P	P	C
Zavrelimyia nubila (Meigen, 1830)		C	C	P		C		C	N Isl
Telmatogeninae									
Thalassomyia frauenfeldi (Schiner, 1856)	P	P	P	P		P	P	P	
Previous records (P)	4	7	13	11	11	13	29	11	1
Confirmed in island (C)	1	13	3	2	0	4	0	19	1
New in island (N Isl)	4	5	6	6	0	4	0	5	14
New in Azores (N Az)	0	3	2	1	0	1	0	5	2
Total species	**9**	**28**	**24**	**20**	**11**	**22**	**29**	**40**	**18**

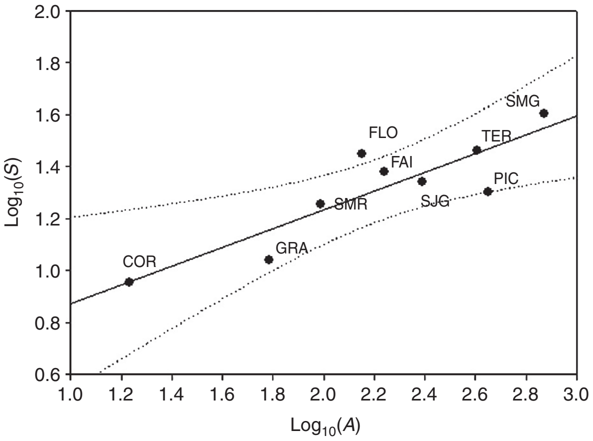

Fig. 3. Species-area curve Log $(S) = 0.5135 + 0.3597*\log\ (A)$. Regression line indicates a significant linear relationship at $P < 0.002$ and $R^2 = 0.78$. Dot lines are 99% interval confidence.

As a result of the collection and examination of pupal exuviae, this study confirmed the presence of 21 species listed by previous authors (Frey, 1944; Stora, 1945; Freeman, 1959; Kehlmaier, 1998; Murray *et al.*, 2004; Diaz *et al.*, 2005). Of the six new records for the Azores, five were exclusive to lotic systems.

Patterns of insular faunal assemblage are the result of factors related to island geography (*e.g.* area, latitude, altitude, isolation) and island ecology (*e.g.* geology, biotope availability, land use), but also reflect the biological characteristics of colonizing organisms (*e.g.* mobility, colonization capability, life cycle). Patterns of organism dispersal in oceanic systems are related to ocean currents, predominant wind patterns (trade winds, hurricane tracks), the geographical position of islands (acting as possible stepping stones) and bird migration routes (mainly eggs attached to feet and feathers). Bilton *et al.* (2001) separated different mechanisms of dispersal into two groups: (1) the active dispersal that self generates movements and (2) the passive dispersal that is achieved by the use of an external agent. In Azorean freshwater systems dispersal by active or passive drift takes place at the reach scale, over time scales, may allow successful colonization of freshwater system. Chironomidae as active flying adults can disperse over larger areas, allowing the colonization of other freshwater systems.

The increase in chironomid species richness with increasing island area is consistent with the observations reported by Borges *et al.* (2005) for epigean arthropods, canopy arthropods and epigean bryophytes in Azores. It is also in agreement with the area-diversity relationship of the equilibrium theory of island biogeography (MacArthur and Wilson, 1967). The theory postulates that the number of species (S) is related to the surface area (A) by the equation $S = CA^z$, where C is a constant that varies among taxa and z is an empirical constant. The z value found for chironomidae species in this study is 0.36, similar to the value determined by MacArthur and Wilson (1967) for oceanic islands (oceanic islands varies between 0.24 to 0.34), indicating the rate at which the species

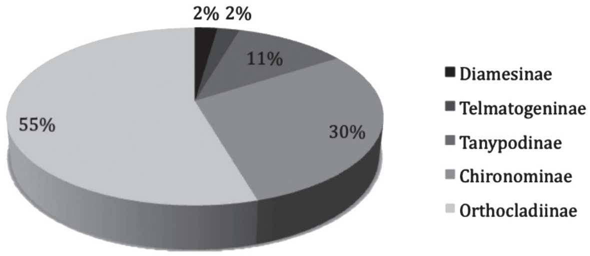

Fig. 4. Representation of subfamilies of chironimids in the Azores archipelago.

richness increases with island area. However, in the case of freshwater invertebrates, the quantity of freshwater is also a vital consideration. For example, the high species richness of Flores Island (Fig. 3) may be due to the availability of a very large quantity of freshwater habitats in relation to its surface area, providing favourable colonization conditions for incoming species. In spite of its small area Flores has several lakes, permanent streams, wetlands and peat bogs. It is also the island with the highest levels of precipitation in the Azores archipelago.

As previously mentioned, the Azorean Chironomid fauna is typically Palaearctic, with widespread species that exhibit great dispersal ability. The lack of single-island endemic chironomid species within the Archipelago compared to the flora, estimated at 7.2% of endemic species (Borges *et al.* 2005), indicates substantial inter-island chironomid dispersal capacity.

All European freshwater ecologists should be familiar with the Water Framework Directive – WFD, which establishes a framework for Community action in the field of water policy. The WFD legislates the provision of mechanisms to prevent further deterioration, and to protect and enhance the status of aquatic ecosystems. The Azores, as a Portuguese autonomous region is obliged to implement the WFD, despite the relatively increase in recent studies of the Azorean macroinvertebrate lotic communities (*e.g.* Murray *et al.*, 2004; Raposeiro and Costa, 2004; Gonçalves *et al.*, 2005) applied a range of well known macroinvertebrate biotic indices to the freshwater fauna of the archipelago, but achieved disappointing results due to the particularities of this distinctly insular local fauna. The Chironomidae is the most abundance and diverse macroinvertebrate family occurring across several types of freshwater systems of the Azores Archipelago, constituting a promising candidate for ecological assessment. For example the Chironomid Pupal Exuviae Technique (CPET) could be possibly be tested and adapted in the archipelago. CPET is based upon the premise that aquatic chironomid larvae are exposed to local environmental conditions and that the winged adults ensure effective dispersal and colonisation and was successfully applied to Madeiran lotic systems (Hughes, 2003).

Acknowledgements. Part of this study was financed by Fundação para a Ciência e Tecnologia (FCT - SFRH / BD / 28798 / 2006). We thank Dr. João Ramos and João Brum for collecting part of the chironomid pupal exuviae data and Dr. Paulo Borges for helpful comments and suggestions that improved the scope and content of the manuscript.

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