

Biogeography and lake morphometry drive diatom and chironomid assemblages' composition in lacustrine surface sediments of oceanic islands

Cátia Lúcio Pereira^{1*}, Pedro Miguel Raposeiro¹, Ana Cristina Costa¹, Roberto Bao², Santiago Giralt³, Vítor Gonçalves¹

¹ CIBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, InBIO Laboratório Associado, Pólo Açores - Departamento de Biologia da Universidade dos Açores, Ponta Delgada, Portugal

e-mail: catiaalpereira@gmail.com

² Faculty of Sciences, University of A Coruña, A Coruña, Spain

³ Institute of Earth Sciences Jaume Almera (ICTJA-CSIC) Barcelona, Spain

Hydrobiologia (2014) 730:93–112 Primary Research Paper

Received: 17 August 2013 / Revised: 7 February 2014 / Accepted: 9 February 2014 / Published online: 21 February 2014

Cite this article as:

Pereira, C.L., Raposeiro, P.M., Costa, A.C., Bao, R., Giralt, S., Gonçalves, V., 2014. Biogeography and lake morphometry drive diatom and chironomid assemblages' composition in lacustrine surface sediments of oceanic islands. *Hydrobiologia* 730, 93-112. doi: 10.1007/s10750-014-1824-6

The final publication is available at Springer via <https://doi.org/10.1007/s10750-014-1824-6>

Abstract

Subfossil biotic assemblages in lakes' surface sediments have been used to infer ecological conditions across environmental gradients. Local variables are usually the major drivers of assemblage composition, but in remote oceanic islands biogeographic filters may play a significant role. To assess the contribution of local and regional filters in the composition of subfossil diatom and chironomid assemblages in surface sediments, 41 lakes in Azores archipelago were studied and related to environmental variables. Ordination techniques were used to identify the forcing factors that best explain the composition of these assemblages. Both assemblages are influenced by multiple limnological variables (conductivity, pH and nutrients). However, diatom assemblages differed mainly in the proportion of planktonic versus benthic species along lakes' depth gradient while chironomids differed significantly among islands but not among lake depths. Thus, biogeographic filters play an important role in shaping islands' freshwater communities, particularly insect ones, more influenced by geographic variables. Results demonstrate the accuracy and potential of biotic remains in sediments for applied studies of lake ecology, trophic status, climatic trends and ecological reconstruction and evolution of lakes. In the Azores, the application of this information for the development of inference models is envisaged as a further step to accomplish these goals.

Keywords: Azores; Chironomid assemblages; Diatom assemblages; Local and regional filters; Oceanic islands; Surface sediments

Electronic supplementary material The online version of this article (doi:10.1007/s10750-014-1824-6) contains supplementary material, which is available to authorized users.

Handling editor: Jasmine Saros

Introduction

In many volcanic oceanic islands, such as the Azores archipelago, lakes represent an important touristic attraction. Beautiful lakes, waterfalls and lush vegetation are important and prized landscape elements. Lake ecosystems provide several services including: supporting (e.g. role in nutrient cycling and primary production, predator–prey relationships and ecosystem resilience), regulatory (e.g. maintenance of water quality—natural filtration and water treatment), cultural (e.g. recreation, tourism and existence values), and provisioning services (e.g. water—quantity and quality—for consumption use); therefore, contributing to regional economy (Costanza et al., 1997). The management of these habitats requires the understanding of their structure and function and the identification of drivers of change. The islands of the Azores archipelago are particularly rich in freshwater ecosystems, with 88 lakes having a total surface area equivalent to 9.5 km², covering 0.4% of the Azores area (Porteiro, 2000; Cruz et al., 2006, 2010). The effect of environmental and human-induced pressures has been constantly increasing since the archipelago's colonization in the fifteenth century, and includes changes in land use (Porteiro, 2000; Gonçalves, 2008; Connor et al., 2012), fish introductions (Skov et al., 2010; Buchaca et al., 2011) and large-scale external processes such as the recent climate warming (Buchaca et al., 2011). The Azores archipelago is located at the centre of the southern extreme of the dipole of the North Atlantic Oscillation (NAO) (Detenbeck et al., 1996), thus particularly sensitive to global change (Andrade et al., 2008).

The combination of all these factors will exert a considerable influence on the abiotic structure of the lake ecosystems, and will act as substantial stressors to aquatic biota in

these islands. Thus, the diversity and taxonomic composition of local communities result from a balance between local (e.g. environmental filtering and biotic interactions) and regional factors (e.g. dispersal-related processes) (Vanormelingen et al., 2008; Göthe et al., 2013). Regional variation in environmental conditions influences community composition as species sort themselves along environmental gradients, but this is regulated by dispersal rates: high dispersal rates allow species to reach all localities with suitable conditions, producing a close relationship between the regional distribution of species and the environmental conditions (Vanormelingen et al., 2008; Capers et al., 2010). Due to the remote location of many of these Azorean lakes and associated logistic constraints, it is often difficult to document biotic and abiotic changes on a regular monitoring basis. The lack of this long-term data in the region makes paleolimnology a useful tool to assess the lake's response to historical environmental change and to impacts caused by human activity (Smol, 2008).

Lacustrine sediments are excellent archives of past environmental changes because they preserve a record of past chemical conditions, such as pH (e.g. Battarbee et al., 2005), salinity (e.g. Chen et al., 2009), nutrient levels (e.g. Bigler et al., 2007), precipitation (e.g. Nichols et al., 2009), temperature (e.g. Francis et al., 2006), and land management practices (e.g. Hyodo et al., 2008). The remains of organisms in the sedimentary record are commonly used to reconstruct environmental changes, but previous studies relating modern distributions of organisms with environmental variables are necessary to infer precise past environmental conditions (Birks, 2012). The diversity of diatoms and chironomid communities and their rapid response to environmental change make them ideal proxies for paleoenvironmental

reconstructions (Battarbee et al., 2001; Bigler et al., 2006; Francis et al., 2006; Millet et al., 2010; Williams et al., 2012); since their remains are usually well preserved in the Azorean lakes sediments (Gonçalves, 2008; Skov et al., 2010; Buchaca et al., 2011), they are excellent candidates to reveal the main ecological changes that could have taken place in these Azorean ecosystems. On the other hand, they have been included as part of the biological indicators described in the European Water Framework Directive (WFD, European-Parliament, 2000) for the establishment of reference conditions and ecological status classes for European waters.

The Azores is a typical oceanic archipelago (i.e., without any foundation of continental rock, formed as the result of volcanic action), but it is unique for having lakes that occur across a wide gradient of biological, climatic and anthropogenic conditions, from the heavily human-impacted to the relatively pristine lakes. The Azores archipelago can serve as a privileged ‘natural’ experiment to examine the factors that influence the distribution and composition patterns of freshwater diatoms and chironomids in islands located far from mainland. We present the first study that explores the distribution of subfossil diatom and chironomid assemblages in surface sediments from lakes in the North Atlantic oceanic islands and relates them to the main environmental variables.

Methodology

The study area: the Azores

The nine islands and several islets that make up the Azores archipelago are located in the Northeast Atlantic Ocean (latitude: 36°55′–39°43′ N; longitude: 24°46′–31°16′ W). Due to the geographical dispersion of the islands, the archipelago is divided into three groups: the Eastern (Santa Maria and São Miguel islands), the Central (Terceira, Graciosa, São Jorge, Pico and Faial islands), and the Western (Corvo and Flores islands) groups

(Fig. 1). The archipelago spans along 615 km and is located approximately 1,300 km west of Portugal and 1,600 km east of North America.

The Azores islands are volcanic in origin (Constância et al., 2000). The archipelago is geologically young (8.12 Ma—Santa Maria Island) (França et al., 2003), but its geology is complex not only because of its volcanic nature, but also due to the existence of complex tectonic plates movements. The landscape of some islands is also marked by the existence of subsidence calderas resulting from the collapse of volcanic cones (Constância et al., 2000). The Azores are particularly rich in lentic habitats, with 88 lakes (Porteiro, 2000) located in the islands of São Miguel, Terceira, Pico and Flores and Corvo. Lakes in Azores can be classified according to their origin: (i) lakes in topographically depressed areas and (ii) lakes within volcanic depressions. Commonly, the latter are located in subsidence or collapsed calderas or in *maars*. Lakes within collapsed calderas show a larger surface area, while those in *maars* are deeper (Constância et al., 2000; Antunes, 2004). The lake surface area ranges between 0.01 ha (Lagoeiro Pico da Água in São Miguel) and 358.69 ha (Lagoa Azul in São Miguel island). Lakes can be classified according to their lake surface area in five categories: very small (68% of the lakes have <1 ha), small (13% have 1–2 ha), medium-sized (9% have 2–10 ha) and large lakes (10% have >10 ha) (Porteiro, 2000). The average lake depth is 9.65 m, ranging between 0.4 (Lagoa do Caldeirão Norte in São Miguel island) and 115 m depth (Lagoa Negra in Flores island) (Porteiro, 2000). Lakes are located between 230 and 1,050 m altitude, with an average of 647 m.

The Azores climate is influenced by the position of the archipelago, which lies in an open oceanic basin, open to the North Pole and the tropics (Ferreira, 1980). The Azores climate can be considered as marine temperate, with low thermal amplitude, high precipitation, high air humidity, and persistent

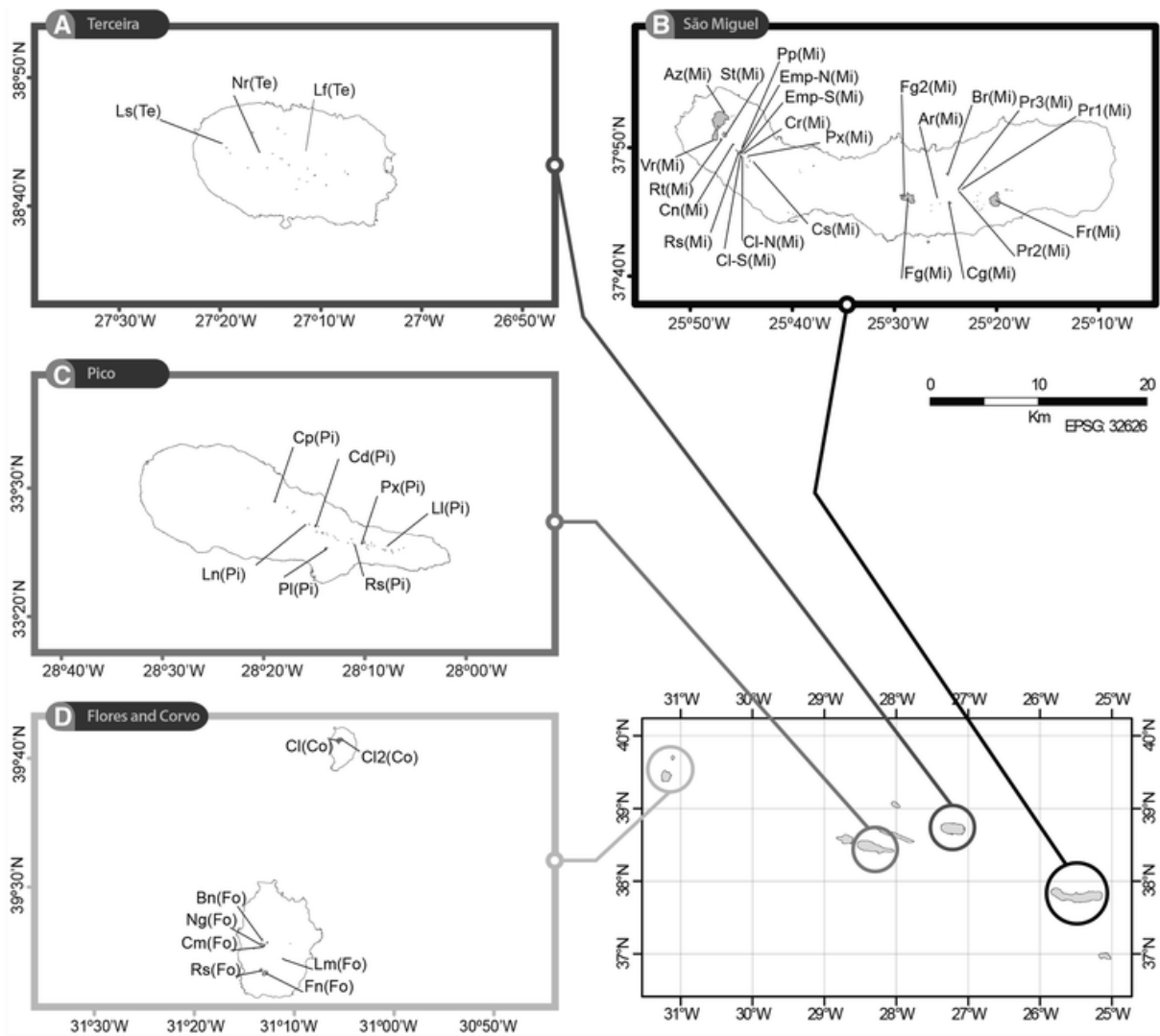


Fig. 1 Location of Azores archipelago and sampled lakes in: **A** Terceira; **B** São Miguel; **C** Pico and **D** Flores and Corvo islands

wind. Most of its climate variability is ruled by the NAO, which has its southern end on the archipelago (Hurrell et al., 2003).

Human colonization of the Azores, and the recent intensification of human activities within catchments (e.g. deforestation, agriculture, urbanization, and introduction of exotic species; Porteiro, 2000), has resulted in eutrophication of many of the lakes. Using multivariate analysis of geomorphological, hydrological and climatic data, and bioindicator assemblages (phytoplankton and benthic diatoms), Gonçalves (2008) identified two main lake groups within the archipelago: (i) shallow lakes, with maximum depth below five metres; and (ii) deep lakes, with maximum depth equals to or greater than five metres depth.

Field sampling and laboratory methods

Between January and July 2012, 41 lakes distributed among five Azorean islands were sampled (Table 1). Water samples for physicochemical analyses were collected at the midpoint of each lake with a Van Dorn bottle (Table 2). The water samples were stored at 4°C in glass bottles until analysis. Water temperature, pH, conductivity and transparency were determined in situ using a multiparametric probe (DKK, model WQC-24) and a Secchi disc, respectively. For both pH and conductivity, equipment was calibrated at each lake prior to measurements. The remaining variables (alkalinity, Kjeldahl nitrogen, total nitrogen, total phosphorous, nitrate, nitrite and silica) were determined in the laboratory at Instituto de Inovação

Table 1 Location and main hydromorphological characteristics of the studied lakes

Island	Lake full name	Code name	Latitude (UTM)	Longitude (UTM)	Alt (m)	LA (km ²)	Z _{max} (m)
São Miguel	Areiro	Ar(Mi)	4,180,720	638,560	630	0.0045	2.70
	Caldeirão Norte	Cl-N(Mi)	4,186,995	609,963	770	0.0018	0.40
	Caldeirão Sul	Cl-S(Mi)	4,186,942	609,998	770	0.0039	0.80
	Canário	Cn(Mi)	4,188,336	609,148	750	0.0178	2.30
	Canas	Cs(Mi)	4,185,822	612,069	570	0.0019	2.40
	Carvão	Cr(Mi)	4,187,054	610,729	680	0.0115	0.40
	Congro	Cg(Mi)	4,179,983	640,242	420	0.0370	17.73
	Empadadas Norte	Em-N(Mi)	4,187,226	610,176	740	0.0175	3.30
	Empadadas Sul	Em-S(Mi)	4,187,092	610,275	750	0.0048	2.45
	Fogo	Fg(Mi)	4,180,740	633,515	574	1.4366	24.20
	Fogo 2	Fg ₂ (Mi)	4,181,113	633,673	574	0.0481	1.98
	Furnas	Fr(Mi)	4,180,144	647,151	280	1.9257	11.50
	Pau-Pique	Pp(Mi)	4,187,922	610,393	690	0.0025	4.50
	Peixe	Px(Mi)	4,186,450	611,232	620	0.0035	1.50
	Pico d'El Rei 1	Pr ₁ (Mi)	4,181,900	642,085	627	0.0010	1.10
	Pico d'El Rei 2	Pr ₂ (Mi)	4,181,654	641,700	648	0.0014	0.60
	Pico d'El Rei 3	Pr ₃ (Mi)	4,181,850	641,567	593	0.0041	1.00
	Rasa da Serra Devassa	Rs(Mi)	4,187,131	609,876	765	0.0331	0.80
	Rasa das Sete Cidades	Rt(Mi)	4,189,125	607,360	545	0.0393	4.53
	Santiago	Sn(Mi)	4,189,551	607,989	360	0.2535	28.75
	São Brás	Br(Mi)	4,184,057	640,014	610	0.0582	2.05
	Azul	Az(Mi)	4,192,418	608,244	260	3.5868	25.35
	Verde	Vr(Mi)	4,189,072	606,554	260	0.8563	23.50
	Terceira	Negro	Nr(Te)	4,287,769	476,631	540	0.0044
Lagoínha da Serreta		Ls(Te)	4,289,038	471,211	777	0.0045	1.60
Vale Fundo		Lf(Te)	4,287,630	483,225	660	0.0005	1.40
Pico	Caiado	Cd(Pi)	4,257,156	390,879	810	0.0545	4.60
	Capitão	Cp(Pi)	4,260,771	384,929	790	0.0266	4.03
	Landroal	Ln(Pi)	4,257,351	389,403	790	0.0064	2.40
	Paul	Pl(Pi)	4,253,987	392,392	790	0.0166	2.90
	Peixinho	Px(Pi)	4,254,695	397,515	870	0.0133	7.80
	Rosada	Rs(Pi)	4,254,495	396,507	900	0.0114	7.10
	Lagoínha do Paul	Ll(Pi)	4,254,080	403,566	510	0.0011	1.70
Flores	Branca	Br(Fo)	4,368,099	652,639	570	0.0475	1.60
	Comprida	Cm(Fo)	4,367,232	652,999	650	0.0544	14.30
	Funda	Fn(Fo)	4,363,277	653,538	360	0.3547	31.90
	Lomba	Lm(Fo)	4,365,545	655,907	650	0.0205	15.27
	Negra	Ng(Fo)	4,367,315	652,676	530	0.1107	115.00
Rasa	Rs(Fo)	4,363,625	652,869	530	0.1031	16.80	
Corvo	Caldeirão	Cl(Co)	4,397,542	661,871	410	0.2307	0.20
	Caldeirão 2	Cl ₂ (Co)	4,397,520	662,391	410	0.0852	2.20
Average					611	0.2316	9.65
Maximum					900	3.5868	115.00
Minimum					260	0.0005	0.20

Table 2

Environmental variables analysed and their categories

Category	Code name	Variable	Units
Spatial	Lat	Latitude	UTM
	Long	Longitude	UTM
Hydromorphological	Alt	Altitude ^a	m
	LA	Lake surface area	km ²
	Z _{max}	Maximum depth	m
Physicochemical	T°C	Water temperature	°C
	T(July)°C	July air temperature	°C
	pH	pH	
	Cond	Conductivity	µS cm ⁻¹
	Alk	Alkalinity ^a	CaCO ₃ l ⁻¹
	Nkj	Kjeldahl nitrogen ^a	mg N l ⁻¹
	TN	Total nitrogen	mg N l ⁻¹
	TP	Total phosphorous	µg P l ⁻¹
	TN/TP	Ratio of total nitrogen and total phosphorous	
	NO ₃	Nitrate	mg NO ₃ l ⁻¹
	NO ₂	Nitrite	mg NO ₂ l ⁻¹
	Si	Silica	mg SiO ₂ l ⁻¹
	Chl <i>a</i>	Chlorophyll <i>a</i> ^a	µg l ⁻¹
	Zsd	Transparency	m
Impact	% Agr	Percentage of agricultural area	%
	% Flo	Percentage of forest area ^a	%
	% Oth	Percentage of other land uses	%

^aEnvironmental variables removed from further analyses

Tecnológica dos Açores (INOVA), according to international standard protocols (APHA, 1998) or to the Portuguese Quality Institute rules. Chlorophyll *a* determination was performed by spectrophotometric methods following the Portuguese norm 4237 (IPQ, 1997), and the concentrations were determined according to the method of Lorenzen (1967). Data on July air temperature were retrieved from the CIELO model, which was developed to generate local scale climate variables from meteorological surface stations measurements, allowing a generalization of meteorological information to all the territory as well as a local scale climatic characterisation of island surface (Azevedo, 1996; Azevedo et al., 1998, 1999a, b). This model was developed in a Geographic Information

System (GIS) and tested in the Azores archipelago.

Surface sediments were collected using a gravimetric corer (UWITEC-90mm) in three different locations from each lake, one always close to its maximum depth. The uppermost 1–2 cm of the sediments was sampled for diatom and chironomid head capsules.

Samples for diatom analysis were prepared following the procedure of Renberg (1990). Diatom slides were mounted with Naphrax, and at least 500 valves were counted per sample under oil-immersion phase-contrast light microscopy using a ZEISS AXIOIMAGE A1 microscope. A variety of general floras were consulted for diatom identification (Krammer & Lange-Bertalot, 1986, 1988, 1991a, b, 2000), complemented with other literature (Patrick &

Reimer, 1966; Germain, 1981; Krammer & Lange-Bertalot, 1985; Cumming et al., 1995; Camburn & Charles, 2000; Krammer, 2000; Dell'Uomo, 2004). The nomenclature used for the taxa has been updated according to the most recent publications, as indicated in the OMNIDIA v4.2 database (Lecointe et al., 1993). Diatom species abundances are expressed as percentages, calculated using the total number of valves recorded for each sample.

For chironomid analysis, samples were prepared by deflocculating them in 10% KOH at approximately 75°C for at least 15 min (Brooks et al., 2007). The sediments were passed through two sieves of 200 and 90 µm mesh size. Head capsules were hand sorted from a Bogorov counting chamber under a stereo microscope (40× magnification—Zeiss Stemi), mounted in Euparal after dehydration and identified using a microscope (ZEISS AXIOIMAGE A1) at 100×–400× magnification. Identification was largely based on mentum characteristics, as described in Brooks et al. (2007), and was performed to the highest possible taxonomic resolution, commonly species morphotypes. Chironomids were identified following the descriptions of Cranston (1982), Oliver & Roussel (1983), Pinder & Reiss (1983), and Rieradevall & Brooks (2001). Taxonomical nomenclature was updated following Brooks et al. (2007).

Data analysis

To minimize redundancy between environmental variables (Hall & Smol, 1992), if two variables were highly correlated ($r > 0.7$ or $r < -0.7$) (Feld & Hering, 2007), the variable with higher overall mean correlation was excluded from further analysis (Alt, Alk, N_{Kj} and Chl a). The environmental data were $\log(x + 1)$ transformed and also normalized to reduce differences in scale (Clarke & Green, 1988; Clarke & Warwick, 2001). A Principal Components Analysis (PCA), based on 18 environmental variables from an initial set of 22 variables, was performed to identify abiotic gradients and patterns between lakes

using PRIMER 6.0 (Clarke & Gorley, 2006) (Table 2). The percentage abundance data of diatoms and chironomids were square root transformed prior to numerical analyses in order to reduce differences in scale (Clarke & Green, 1988).

We tested for two spatial distribution patterns in diatoms and chironomids: (i) between islands (fixed, five levels; Flores, Corvo, Pico, Terceira, and São Miguel), and (ii) lake depth group (fixed, two levels: deep and shallow) according to Gonçalves et al. (2008). To test for differences and the level of significance between and within identified groups of environmental and fossil samples, a permutational multivariate analysis of variance—PERMANOVA (Anderson et al., 2008) was used. PERMANOVA test is analogous to the multivariate analysis of variance (MANOVA), which, however, is too stringent in its assumptions for most ecological multivariate data sets (McArdle & Anderson, 2001). The analyses were run in the PERMANOVA+ for PRIMER software (Clarke & Gorley, 2006; Anderson et al., 2008).

In order to a better visualization of the most abundant diatom and chironomid taxa in the surface sediments, diagrams were originated with C2 programme (Juggins, 2003). In addition, a SIMPER analysis was used to determine which taxa contributed the most to the differences between groups and to the similarity within each group (Clarke & Gorley, 2006).

A detrended correspondence analysis (DCA) was performed in order to explore the type of relationship between the assemblages and the environmental data. The first axis of the DCA analysis had a gradient length (λ) of 3.31 standard deviation (SD) units for chironomid assemblages and 5.53 SD for diatom assemblages, and thus the data were suitable for unimodal analysis (Leps & Smilauer, 2003). The direct relationship between assemblages and the environmental data was explored by unimodal canonical correspondence analysis (CCA) using biplot

Table 3 Results of two-factor PERMANOVA on environmental data and diatom and chironomid fossil assemblages: bold *F* values indicate significant *P* values

	Source	df	SS	MS	Pseudo- <i>F</i>	<i>P</i> (perm)
Environmental	Typology	1	264.18	264.18	2.7174	0.028
	Island (lake depth group)	5	559.09	111.82	12.879	<0.001
	Res	114	989.75	8.682		
	Total	120	1,920			
Diatoms	Typology	1	53,833	53,833	6.8042	0.003
	Island (lake depth group)	5	44,597	8,919.5	4.9517	<0.001
	Res	114	2.05E+05	1801.3		
	Total	120	3.18E+05			
Chironomids	Typology	1	11,684	11,684	1.6749	0.162
	Island (lake depth group)	5	39,319	7,863.7	4.9365	<0.001
	Res	114	1.82E+05	1,593		
	Total	120	2.36E+05			

centred on interspecies distances. Forward selection of the exploratory variables was used in order to find the minimal subset of the best exploratory variables that account for the assemblages' data and to rank the importance of the environmental variables for determining these data (Leps & Smilauer, 2003). The statistical significance of the relationship between the assemblages and the whole set of environmental variables in a constrained ordination model was evaluated using Monte Carlo permutation test (999 permutations), which allowed us to judge the statistical significance of each selected variable in a regression model for a model selection. DCA and CCA and forward selection were performed using CANOCO 5.01 software (Braak & Smilauer, 2012).

Results

Environmental characterisation

The studied lakes exhibit features varying from acidic to alkaline waters (pH ranging between 5.41, Lagoínha da Serreta, and 8.85, Lagoa Pico d'el Rei). Conductivity ranged between 27.30 $\mu\text{S cm}^{-1}$ (Lagoa Fogo 2) and 128.75 $\mu\text{S cm}^{-1}$ (Lagoa das Furnas), with a mean of 58.38 (4.54 SE) $\mu\text{S cm}^{-1}$. In general, lakes of larger surface area and depth were those with higher pH and conductivity values.

According to some trophic level indicators, such as total phosphorous, chlorophyll *a* concentrations and water transparency (for trophic level indicators limits see Nümborg, 1996 and Smith et al., 1999), Azorean studied lakes can be considered oligo-mesotrophic to hypereutrophic ($2.5 > \text{TP} > 385 \mu\text{g P l}^{-1}$; $1.03 > \text{Chla} > 465.43 \mu\text{g l}^{-1}$; $0.2 > \text{SD} > 3.98 \text{ m}$) (Online Resource 1).

The PERMANOVA global test showed significant differences between shallow and deep lakes for the environmental parameters (pseudo-*F* = 2.72, *P* < 0.028), and within lake depth group on the different islands (pseudo-*F* = 12.87, *P* < 0.001) (Table 3). The major environmental gradients, revealed from the results of the PCA, also reflected this pattern. The first two PCA axes explained 39.4% of total variation. The first axis (PC1) is mainly associated with gradients of conductivity, pH and maximum depth. The second axis (PC2) is related to gradients of trophic state indicators, such as water transparency, total phosphorous, nitrate and total nitrogen concentrations (Fig. 2). In the PCA diagram there are two distinct groups of samples, one corresponding to shallow lakes distant from human populations at mostly higher altitudes and having lower mineralization, and another group corresponding to deeper, lower altitude lakes, located closer to human populations with higher mineralization.

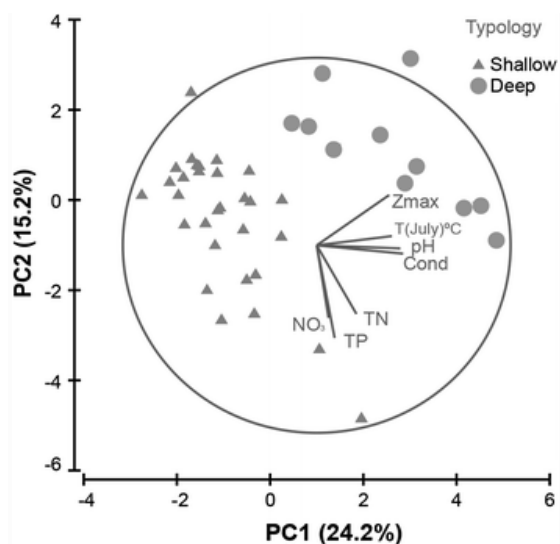


Fig. 2 PCA of all lakes based on environmental variables along axes 1 (PC1) and 2 (PC2). *Solid vectors* represent environmental variables, and the length of the vector is the measure of the importance of the variable. Only variables with loadings >0.3 on at least one of the first two PC axes are represented (abbreviations see Table 2)

Diatom assemblages

A total of 207 diatom taxa from 55 genera were identified from the surface sediments of the 41 sampled lakes. The most representative genera were *Navicula* s. l. (13.53%), *Nitzschia* (9.18%), *Pinnularia* (6.28%), *Fragilaria* s. l. (4.35%) and *Eunotia* (4.35%). From the 207 diatom taxa identified, none occurred in all 41 studied lakes, and only 37 taxa occurred in more than 50% of the lakes. These included species such as *Diademesmia contenta* (Grunow ex Van Heurck) Mann, *Achnantheidium minutissimum* (Kützing) Czarnecki, *Nitzschia palea* (Kützing) W. Smith, *Eunotia paludosa* Grunow in Van Heurck, *Brachysira neoexilis* H. Lange-Bertalot, *Frustulia crassinervia* (Brebisson) Lange-Bertalot & Krammer, *Navicula notha* Wallace, *Nitzschia gracilis* Hantzsch, *Brachysira brebissonii* Ross in Hartley, and *Encyonema neogracile* Krammer, which were among the most ubiquitous diatoms. A total of 49 taxa had a sporadic occurrence, occurring at only one sampling site. A maximum of 90 taxa was recorded in Px(Pi) and a minimum of 23 in Vr(Mi), with a mean richness of 52 taxa per

lake. Species such as *Aulacoseira ambigua* (Grunow) Simonsen, *Stauroforma exiguiformis* (Lange-Bertalot) Flower, Jones & Round, *Brachysira brebissonii*, *Brachysira neoexilis*, *Tabellaria flocculosa* morph 1, *Eunotia incisa* Gregory, and *Aulacoseira granulata* (Ehrenberg) Simonsen were among the taxa with the highest mean abundances (Fig. 3).

CCA ordination separates the sampled lakes in two major groups of distinct communities (Fig. 4), along the CCA axis 1 ($\lambda = 0.73$, 21.7% of variance explained) and axis 2 ($\lambda = 0.32$, 9.42% of variance explained), one on the right of the CCA, which includes most of the deep lakes [Lm(Fo), Cm(Fo), Fg(Mi), Az(Mi), Vr(Mi), Cg(Mi), Fr(Mi), Sn(Mi), Fn(Fo) and Ng(Fo)], and other comprising the shallow lakes. The PERMANOVA test showed that the differences between these two groups are statistically significant (pseudo- $F = 6.80$, $P < 0.003$), indicating that the structure of diatom assemblages differs considerably with depth. The same occurs within same lake depth groups between islands (pseudo- $F = 4.95$, $P < 0.001$) (Table 3). SIMPER analysis revealed a dissimilarity of 84.91% between shallow and deep lakes. The species that contributed most to the dissimilarity between lake depth groups were *Aulacoseira ambigua*, *Aulacoseira granulata*, *Asterionella formosa*, *Stauroforma exiguiformis*, *Tabellaria flocculosa* morph 1 and *Brachysira brebissonii*. In shallow, lakes surface sediments were dominated by benthic diatoms, whereas in the deeper lakes planktonic taxa such as *Aulacoseira ambigua*, *Asterionella formosa*, *Fragilaria crotonensis* Kitton and *Aulacoseira granulata* were dominant. In general, deep lakes were dominated by planktonic species, whereas in shallow lakes benthic species were predominant (Fig. 3). This pattern is also evident in scores of the diatom assemblages on CCA axes 1 and 2 (Fig. 4). Planktonic species display high CCA axis 1 score, whereas the benthic species presents low scores on the first CCA axis.

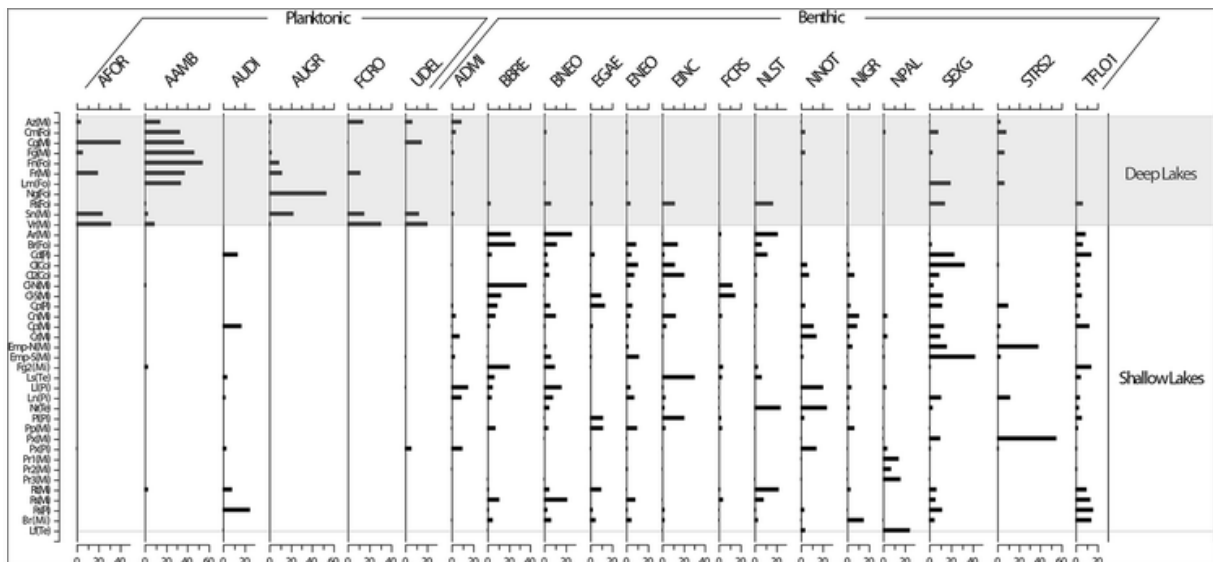


Fig. 3 Distribution of the most abundant diatoms in surface sediments of the sampled lakes. Only the 20 more abundant taxa are represented (taxa codes—see Online Resource 2; sampled lake codes—see Table 2)

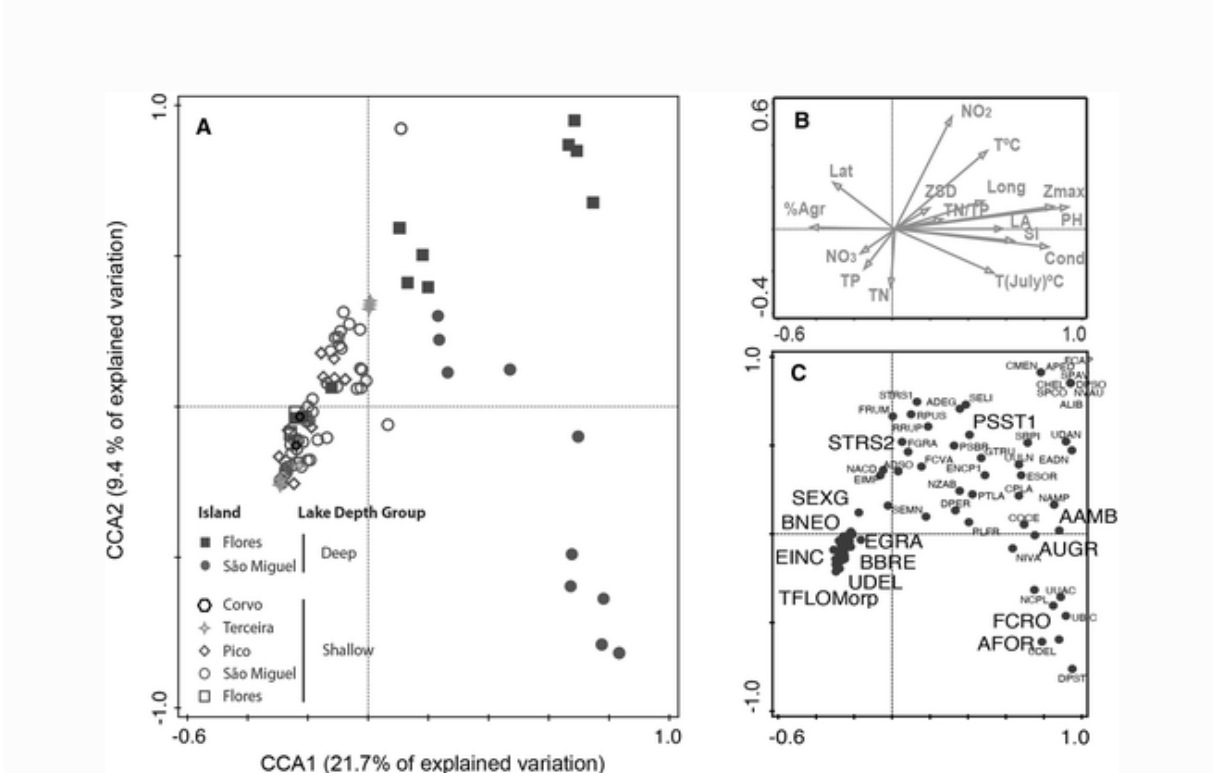


Fig. 4 CCA plots representing the first (X1) and second (X2) axes. **A** Distribution of sampling sites labelled by the corresponding lake depth group and island. **B** Position of environmental variables that best explains the variance among taxa included in the analysis. **C** Distribution of taxa. Taxa that represent 40% of dissimilarity between shallow and deep lakes are represented in capital letters (taxa codes—see Online Resource 2)

After a forward selection 15 environmental variables formed the best set of variables that explained a statistically significant amount of the total variation in the diatom data. According to these, pH and conductivity (explaining 19.1 and 3.4% of the total variance in the diatom assemblages,

respectively; Table 4) showed a high positive correlation with the first CCA axis. The second CCA axis showed a positive correlation with NO_2 (explaining 7.7% of the variance) and a negative correlation with TN (explaining 5.0% of the total variance in the diatom assemblages).

Table 4 Summary of forward selection procedure for environmental variables performed in diatom assemblages

Environmental variable	Explains %	Contribution %	Pseudo- <i>F</i>	<i>P</i>
Cond	15.8	20.4	9.2	0.001*
pH	8.4	10.9	5.3	0.001*
NO ₂	7.7	10.0	5.3	0.001*
<i>T</i> °C	5.3	6.9	3.9	0.001*
Long	4.4	5.7	3.4	0.002*
TP	4.8	6.2	3.9	0.002*
%Agr	3.9	5.1	3.4	0.002*
TN	4.1	5.4	3.8	0.002*
<i>T</i> °C (July)	3.4	4.4	3.3	0.002*
Lat	3.2	4.1	3.3	0.002*
<i>Z</i> _{max}	3.3	4.2	3.6	0.002*
LA	3.5	4.6	4.2	0.002*
NO ₃	3.0	3.9	3.8	0.002*
ZSD	2.9	3.8	4.0	0.002*
Si	1.8	2.4	2.7	0.002*
TN/TP	1.6	2.1	2.3	0.006

For each selected variable, percentage of variance explained, percentage of contribution, pseudo-*F* and *P* values (* *P* > 0.05 after Bonferroni correction)

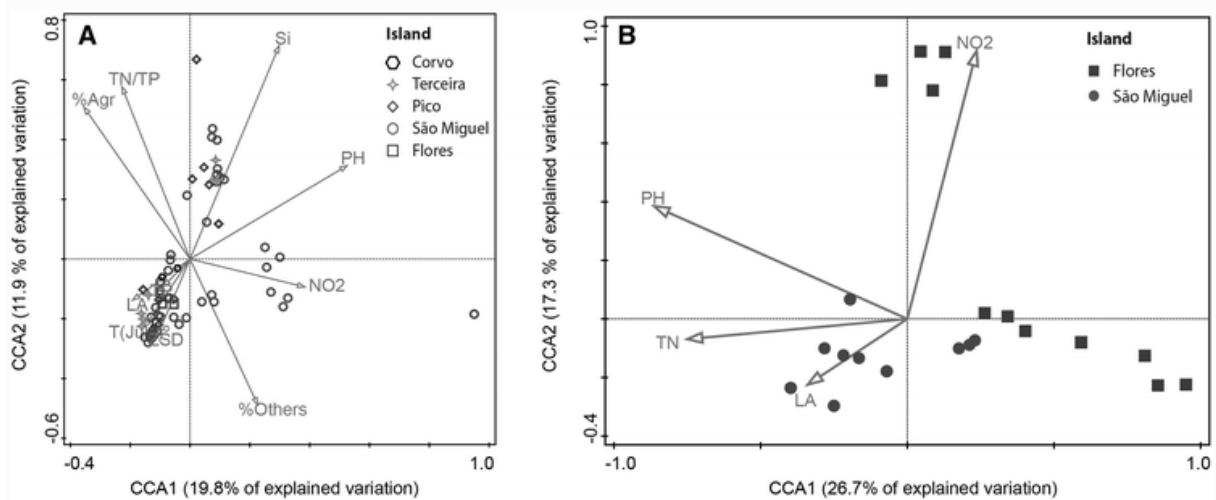


Fig. 5 CCA plots representing the first (X1) and second (X2) axes. **A** Distribution of shallow sampling lakes and **B** distribution of deep sampling lakes

Figures 2 and 4 indicate large separations in environmental variables and the diatom assemblages in shallow and deep lakes. In order to reveal possible relationships between other environmental variables and diatom assemblages, two additional ordinations of diatom species data, one using species data just from shallow sites (Fig. 5A) and other

with just data from deep sites (Fig. 5B). A subsequent forward selection procedure for each set of new ordinations was performed to identify possible differences within the predominant benthic and the predominant planktonic diatom assemblages among different islands.

Table 5 Summary of forward selection procedure for environmental variables performed in diatom assemblages from shallow lakes

Environmental variable	Explains (%)	Contribution (%)	Pseudo- <i>F</i>	<i>P</i>
pH	9.8	14.8	3.4	0.002*
%Agr	10.2	15.4	3.8	0.002*
NO ₂	7.7	11.7	3.1	0.002*
Si	7.1	10.8	3.0	0.002*
TP	6.1	9.3	2.8	0.002*
ZSD	6.3	9.6	3.1	0.002*
T°C (July)	5.2	7.9	2.7	0.004*
LA	5.3	8.1	3.0	0.002*
%Oth	4.7	7.1	2.9	0.002*
TN/TP	3.6	5.4	2.3	0.004*

For each selected variable, percentage of variance explained, percentage of contribution, pseudo-*F* and *P* values (* *P* > 0.05 after Bonferroni correction)

Table 6 Summary of forward selection procedure for environmental variables performed in diatom assemblages from deep lakes

Environmental variable	Explains (%)	Contribution (%)	Pseudo- <i>F</i>	<i>P</i>
pH	23.5	36.3	4.9	0.002*
NO ₂	18.2	28.1	4.7	0.002*
LA	12.7	19.6	3.9	0.002*
TN	6.4	9.9	2.1	0.006*

For each selected variable, percentage of variance explained, percentage of contribution, pseudo-*F* and *P* values (* *P* > 0.05 after Bonferroni correction)

For shallow lakes, the first two statistically significant canonical axes explained together 31.64% ($\lambda_1 = 0.41, \lambda_2 = 0.25$) of the total variation (2.09) in diatom assemblages from shallow lakes. After forward selection 10 environmental variables formed the best set of variables that explained a statistically significant amount of the total variation in shallow lakes diatom data (Table 5). Percentage of agriculture area (%Agr; regional scale filter) showed a negative correlation (explaining 10.2% of total variance) and pH (local scale filter) showed a positive correlation (explaining 9.8% of total variance) with the first CCA axis. The second CCA axis was related with local scale filters, showing a negative correlation with NO₂ and a positive correlation with Si, explaining 7.7 and 7.1%, respectively, of total variance in the diatom assemblages from shallow lakes (Table 5).

For deep lakes, the first two statistically significant canonical axes explained together 43.95% ($\lambda_1 = 0.51, \lambda_2 = 0.33$) of the total variation (1.90) in diatom assemblages from deep lakes. After forward selection 4 environmental variables formed the best set of variables that explained a statistically significant amount of the total variation in deep lakes diatom data (Table 6). The first CCA axis accounted for 26.65% of the explained variation in the diatom assemblages from deep lakes and was strongly related to local scale variables such as pH and NO₂ concentration (explaining 23.5 and 18.2%, respectively, of total variance in deep lakes diatoms). While the second axis was related to lake area (regional scale variable), explaining 12.7% of total variation and to TN (local scale variable) and 6.4% of total variation in the diatom assemblages from deep lakes (Table 6).

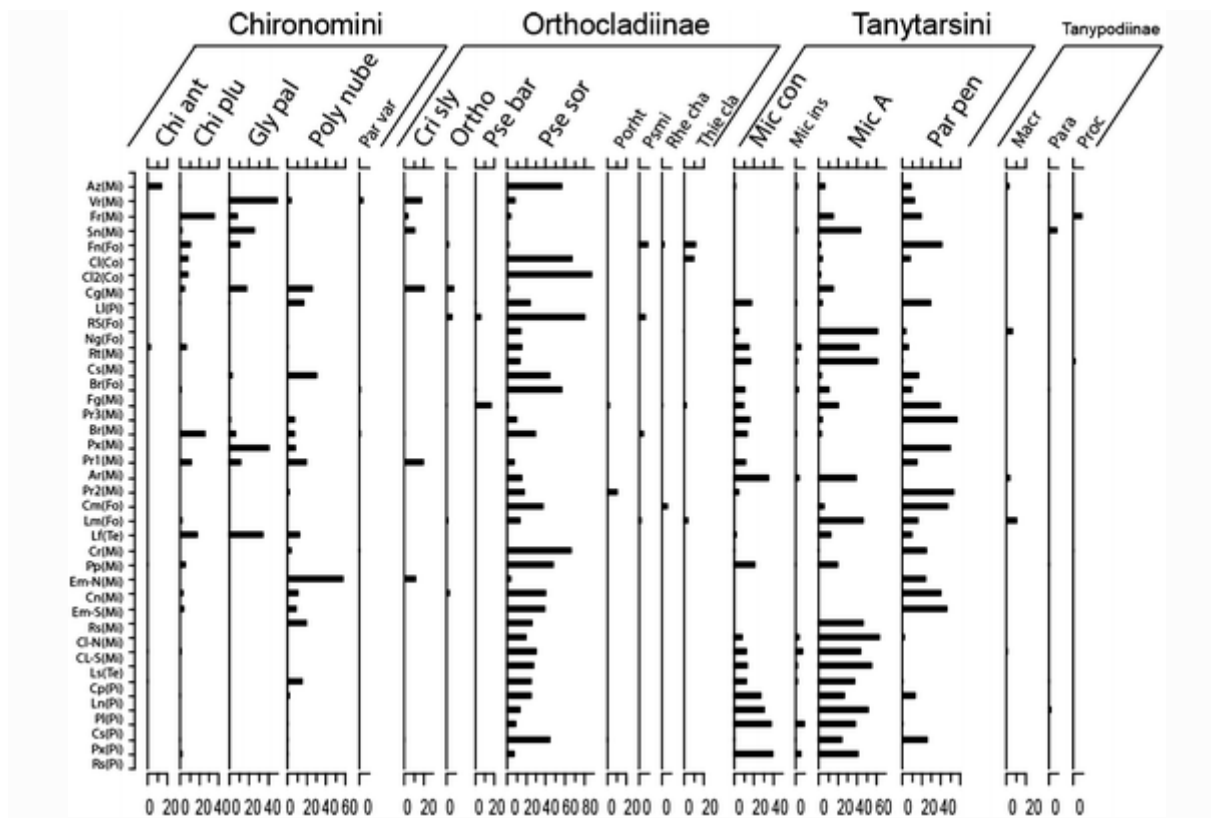


Fig. 6 Distribution of the most abundant chironomid taxa in surface sediments of the sampled lakes. Only the 20 more abundant taxa are represented (taxa codes—see Online Resource 3; sampled lake codes—see Table 2)

Chironomid assemblages

A total of 27 chironomid taxa were identified in the surface sediments of the sampled lakes, with the Orthocladiinae (12 taxa) showing the highest richness, followed by Chironominae (11 taxa) and Tanytopodiinae (4 taxa). None of the taxa occurred in all lakes. *Psectrocladius sordidellus* type (Pse sor) and *Micropsectra* type A (Mic A) were the dominant taxa, occurring in more than 80% of the lakes (Fig. 6). Other taxa present in reasonable abundances in most samples were *Paratanytarsus penicillatus* type (Par pen) and *Micropsectra contracta* type (Mic con). Many taxa were restricted to specific lakes. For example, *Zavreliomyia* (Zavre) occurred exclusively in Cd(Pi), while *Glyptotendipes barbipes* type (Gly bar) is restricted to Br(Mi). Abundance of head capsules of chironomid larvae showed large variations in the different studied lake sediments, ranging from 2.5 (Ng(Fo)) to 22.3 (Cd(Pi)) head capsules per cubic centimetre of sediment. Taxon richness values of the

chironomid assemblages ranged a maximum of 12 taxa in Br(Mi) and a minimum of 3 in Cl2(Co) and Px(Mi), with a mean value of seven taxa per lake.

PERMANOVA analyses revealed large and significant differences in the composition and structure of the chironomid community between islands [Island (lake depth)—pseudo- $F = 4.94$; $P < 0.001$], but not between lake depth groups (lake depth groups—pseudo- $F = 1.67$; $P = 0.162$). This is also shown in the biplot of the CCA, where samples do not display a clear pattern segregating shallow from deep lakes (Fig. 7). The first axis ($\lambda_1 = 0.45$, 16.36% of variance explained), however, does separate more anthropogenically impacted lakes such as Fr(Mi), Vr(Mi), Px(Mi), Cg(Mi) and Lf(Te) from more pristine ones [e.g. Rs(Fo), Cd(Pi), Fg(Mi) and Ls(Te)]. The second axis ($\lambda_2 = 0.31$, 11.13% of variance explained) seems to separate lakes according to their geographical position.

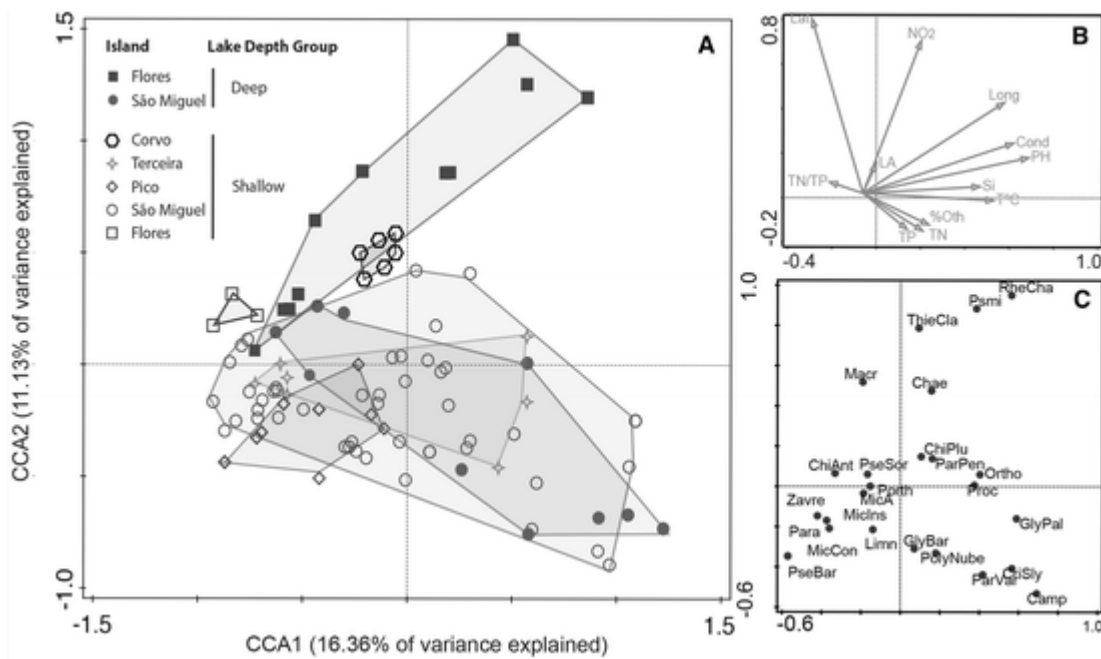


Fig. 7 CCA plots representing the first (X1) and second (X2) axes. **A** Distribution of sampling sites labelled by the corresponding lake depth group and island. **B** Position of environmental variables that best explains the variance among taxa included in the analysis. **C** Distribution of chironomid taxa (taxa codes—see Online Resource 3)

SIMPER analysis indicated that the average similarity was higher in Corvo island (71.36%), followed by Pico (67.42%), Terceira (47.61%), Flores (44.25%) and São Miguel (40.64%), suggesting a greater heterogeneity on the islands with deeper lakes. Four taxa contributed extensively to the differences between islands (*Psectrocladius sordidellus* type (Pse sor); *Micropsectra* type A (Mic A), *Paratanytarsus penicillatus* type (Par pen) and *Micropsectra contracta* type (Mic con)), accounting for 63.52% of the overall dissimilarity between Corvo and São Miguel islands, and 45.77% between Terceira and Pico (see Online Resource 4). Average dissimilarities between islands were significantly correlated with the lineal distances in km between them ($R = 0.83$; $P < 0.003$; $n = 10$). This pattern is evident in Fig. 7, which shows the scores of the common chironomid assemblages on CCA axes 1 and 2. Taxa such as *Thienemanniella clavicornis* type (Thie cla), *Macropelopia* (Macr), *pseudosmittia* (Psmi) and *Rheocricotopus* (Rhe) are mostly influenced by CCA axis 2, which are related to differences in latitudinal gradient. This axis can, therefore, be interpreted as being related

to differences in latitude. On the other hand, *Camptocladius* (Camp), *Cricotopus sylvestris* type (Cry sly), *Glyptotendipes* (Gly) and *Polypedilum* (Poly) morphotypes show a strong relationship with CCA axis 1, occurring predominantly in anthropogenically impacted lakes. By contrast, the *Macropelopia*, *Zavreliomyia* (Zavre), *Paramerina* (Para), *Micropsectra* (Mic) and *Psectrocladius* (Pse) morphotypes are characterised by low scores on the first CCA axis and were more abundant in pristine lakes.

In the initial CCA with all the 17 exploratory variables, the first two statistically significant canonical axes explained together 28% ($\lambda_1 = 0.46$, $\lambda_2 = 0.31$) of the total inertia (2.76) in the chironomid assemblages. Among the 17 determinants, 12 environmental variables formed the best set of variables, after forward selection, which explained a statistically significant amount of the total variation in the chironomid data. Using these 12 variables, the first two CCA axes explained 45.8% of the relationship between the chironomid assemblage and the measured environmental variables, and 27.5% ($\lambda_1 = 0.45$, $\lambda_2 = 0.31$) of the total variability in the community data.

Table 7 Summary of forward selection procedure for environmental variables performed in chironomid assemblages

Environmental variable	Explains (%)	Contribution (%)	Pseudo- <i>F</i>	<i>P</i>
Cond	11.1	16.6	6.1	0.001*
Lat	8.8	13.1	5.3	0.001*
LA	8.5	12.8	5.6	0.002*
NO ₂	5.8	8.6	4.0	0.002*
%Oth	5.2	7.8	3.9	0.002*
Si	5.2	7.8	4.2	0.002*
TP	3.5	5.3	3.0	0.002*
Long	2.8	4.3	2.5	0.002*
<i>T</i> °C	2.6	3.9	2.1	0.008
TN	2.5	3.7	2.2	0.006
TN/TP	2.2	3.3	2.0	0.002*
pH	1.9	2.9	1.8	0.014

For each selected variable, percentage of variance explained, percentage of contribution, pseudo-*F* and *P* values (* *P* > 0.05 after Bonferroni correction)

The first CCA axis accounted for 16.4% of the explained variation in the chironomid assemblages and was strongly related to local scale variables such as pH and NO₂ concentration (explaining 12.0 and 5.1%, respectively, of the total variance in the chironomid assemblages; Table 7), while the second axis was related to regional scales variables such as latitude (Lat) or lake area (LA) (explaining 9.0 and 6.6%, respectively, of the total variance in the chironomid assemblages).

Discussion

The 41 lakes examined in this study exhibit a wide range of physical and chemical properties, reflecting the large geographical area, variety of biogeographic filters and environmental gradients that structure lake communities over several spatial scales. They constitute an ideal set to test hypotheses about the individual and combined effects of regional and local scale filters on the composition and distribution of freshwater assemblages.

The archipelago has a simple freshwater community of diatoms and chironomids compared to more diverse continental

systems. For example, 500 diatom taxa were reported from Nebraska lakes (Shinneman et al., 2010), in the United States of America and 329 were registered for Icelandic lakes (Karst-Riddoch et al., 2009); while Bigler et al. (2006) identified 62 chironomid taxa in Swiss lakes and Engels and Cwynar (2011) reported 85 from Massachusetts (northeast USA). These values contrast with the 207 diatom taxa and 27 chironomid taxa found in the present study. In fact, several studies highlight the paucity of freshwater fauna (especially invertebrates) in oceanic islands (Malmqvist et al., 1993; Brasher et al., 2004; Hughes & Malmqvist, 2005), and the Azores archipelago is not an exception (Raposeiro & Costa, 2009; Raposeiro et al., 2009, 2012). The paucity of freshwater organisms in most oceanic islands lakes is a consequence of the biogeographic filters that operate over a range of spatial scales, influencing the colonization of organisms and the events that shape the local freshwater assemblages. These can be: dispersal capacity over oceanic barriers; distance from continental landmasses; predominant wind direction; island size, island age; and local conditions such as water availability, habitat type and quality (e.g.

Bilton et al., 2001; Cowie & Brenden, 2006; Covich, 2009).

Local scale filters on freshwater assemblages

Surface sediment diatom and chironomid assemblages among the Azorean lakes are influenced by a combination of multiple limnological variables that include conductivity, pH, nitrate, total phosphorous and maximum depth, as also observed in similar other studies elsewhere (e.g. Battarbee et al., 2001; Bigler et al., 2006; Holmes et al., 2009; Engels & Cwynar, 2011; Flower et al., 2012).

PERMANOVA results identified significant differences between lake depth groups, both in the physicochemical and biological components. In fact, the PCA for the environmental variables and forward selection routine for biological data revealed that conductivity was the major variable separating the lakes assemblages according to their depth.

It is accepted that the ionic composition and concentration of world surface waters are controlled by three main factors, i.e. the underlying geology, the atmospheric precipitation and the balance between evaporation and the precipitation of salts (Wetzel, 2001). Although studies about the hydrogeochemistry of the Azores lakes and their volcanic settings are rare in the international literature, most of the studied waters are associated with lakes in craters or subsidence calderas, and correspond to fresh and much diluted waters mainly originated from atmospheric precipitation (Cruz et al., 2006). Deep Azorean lakes generally correspond to those showing higher values of nutrient and ion concentrations, being located in collapse or subsidence calderas and maars at low elevation. By contrast, shallow Azorean lakes exhibited low ion and medium nutrient concentrations, being located in explosive craters. This conductivity gradient is highly correlated with altitude, and according to Cruz et al. (2006) and Gonçalves

(2008) this trend suggests that those lakes are strongly influenced by sea-salt spray.

Diatom assemblages show distinct distribution across the different types of lakes. Both benthic and planktonic forms were well represented in the diatom assemblages, as a result of the wide range of lake depths of the studied lakes and, hence, the availability of both littoral and open water habitats. It has been reported that the diatom taxa in sediments from large, deep lakes consist predominantly of planktonic taxa (Marchetto et al., 2004; Bigler et al., 2006), while benthic diatom assemblages dominate shallow lakes (e.g. Karst-Riddoch et al., 2009). Some planktonic diatoms may require stratification of the water column to maintain their position in the euphotic zone (Karst-Riddoch et al., 2009). Results from Azorean shallow lakes suggest that they may not be thermally stratified, or they are simply too shallow to support large planktonic diatom communities. By contrast, planktonic forms were important components of the diatom assemblages in most of the deeper lakes, attaining relative abundances of over 50%. The increased water volume reduces the availability of microhabitats, dominating the pelagic habitat with planktonic taxa (Wang et al., 2012). Comparing these data with phytoplankton data from the same lakes, it is clear that diatoms are quite abundant in phytoplankton for most of the year (see Gonçalves, 2008 and Gonçalves et al., 2009 for further details). In contrast, Chlorophyceae and Desmidiaceae species are the dominant groups of phytoplankton in shallow lakes, Chrysophyceae and Dinophyceae being subdominant (Gonçalves et al., 2008, 2009).

The higher relative abundances of benthic diatom taxa and lower abundances of planktonic diatoms in the shallow lakes relative to the deep lakes accounted for almost 85% of the dissimilarity between the diatom assemblages in deep and shallow lakes. These data complement the available information on the composition of phytoplankton, where diatoms constitute the dominant group in deep

lakes (Gonçalves et al., 2008). Therefore, lake water depth affects diatom assemblage composition mainly through habitat properties and substrate availability, explaining the assemblages collected from Azorean lakes surface sediments. This result highlights the reliability of using Planktonic to Benthic ratios (Wolin & Stone, 2010) for future reconstructions of past lake level fluctuations in Azorean lakes.

In contrast to diatoms, chironomids do not include true planktonic taxa, although, despite being benthic, some stages of instar larvae temporarily could enter in the water column for dispersal (Bigler et al., 2006). In fact, the composition and structure of the chironomid community studied here did not show significant differences between shallow and deep lakes. This is consistent with the other findings of Holmes et al. (2009) and Verbruggen et al. (2011), who showed no clear relationship between chironomid assemblages and water depth. Both lake depth groups were mainly characterised by *Microspectra* type A and *Psectrocladius sordidellus* type contributing to more than 50% for the average similarity. Langdon et al. (2008) identified several large and deep lakes whose deep surface sediments contained mainly littoral head capsules. This observation reinforces the conclusions of Heiri (2004) that the chances of sampling dominant chironomid taxa are somewhat irrespective of the location in the lake in spite of differences in their spatial abundance. At Azorean lakes, chironomid head capsule concentrations were higher in samples from shallow lakes. According to Holmes et al. (2009), these could be explained by the fact that light can penetrate to the bottom of these lakes, supporting larger floral communities, which in turn support larger invertebrate communities compared to those of deeper lakes.

Besides being affected by differences in lake depth, diatom assemblages in our data set also show relationships with other limnological variables, such as pH, nutrient enrichment and

temperature, all factors previously reported as influencing assemblage compositions in several lakes across the world (e.g. Lim et al., 2001; Antoniadis et al., 2005; Verbruggen et al., 2011; Flower et al., 2012; Williams et al., 2012). Nutrients and temperature had, however, a small explanatory value in our data set. At least for nutrients, this is likely a consequence of the comparatively short enrichment gradients encompassed by the Azorean studied lakes, which do not include highly eutrophic and hypertrophic lakes; except Pp(Mi) (TP = 465.43 $\mu\text{g P l}^{-1}$), Pr1(Mi) (TP = 251 $\mu\text{g P l}^{-1}$, Chla = 205.94 $\mu\text{g l}^{-1}$, SD = 0.5 m), Pr2(Mi) (TP = 168 $\mu\text{g P l}^{-1}$, Chla = 58.04 $\mu\text{g l}^{-1}$, SD = 0.6 m), Pr3(Mi) (TP = 385 $\mu\text{g P l}^{-1}$, Chla = 465.43 $\mu\text{g l}^{-1}$, SD = 0.3 m), Br(Mi) (TP = 126.75 $\mu\text{g P l}^{-1}$, Chla = 33.35 $\mu\text{g l}^{-1}$, SD = 0.4 m), and Lf(Te) (TP = 296 $\mu\text{g P l}^{-1}$, Chla = 88.56 $\mu\text{g l}^{-1}$, SD = 0.4 m). Furthermore, the strong gradients in elevation and lake depth may have further obscured any relationship between the fossil assemblages and lake nutrient conditions. For example, the natural gradient of decreasing temperature and nutrient concentrations with increasing altitude is exacerbated by human disturbance (clearance of vegetation and agricultural activities in low lands). This innate covariation confounds relationships between environmental variables and biotic communities (Allan, 2004), especially in lakes that exhibit large altitudinal differences in human impacts. Our results suggested that Azorean shallow lakes are more susceptible to this human disturbance, since their diatom assemblages showed a negative correlation with the surrounding agriculture area (% Agr).

Regional scale filters on freshwater assemblages

Identifying the factors that influence the diversity and taxonomic composition of local communities both on and between islands is an extremely complex process. The results from this study show significant differences between islands in diatom and chironomid assemblages, indicating that regional filters

play an important role in shaping Azorean freshwater communities. The Azores archipelago covers a large area with an enormous variety of biogeographic filters and diatom/chironomid distribution patterns that can be largely explained by these filters. At higher spatial scales, such as among islands, species distribution patterns were largely explained by geographic variables such as latitude and longitude. These results agree with those of Raposeiro et al. (2013), who reported differences in the composition, abundance and structure of freshwater macroinvertebrates communities in Azorean streams between islands related to regional filters such as latitude. Also, Vyverman et al. (2007) suggest that regional (latitude) and global (e.g. historical factors, such as dispersal limitation and migration) filters are mainly responsible for lacustrine diatom distribution patterns.

The percentage of variance explained only by geographic variables (i.e., latitude and longitude) in our study was higher (11.6%) in chironomid assemblages than in diatom assemblages (7.6%), indicating that chironomids are more influenced by these regional filters and that diatoms have a higher dispersal capacity. In fact, only chironomid average dissimilarities among islands revealed a positive correlation with the linear distances between islands. This could be explained by many taxa being shared by neighbouring groups of islands but not by the remaining islands from the archipelago. For example, the *Pseudosmithia* is only represented in surface lake sediments of Flores and Corvo, the Western group of islands, being absent from the others. By contrast, *Polypedilum nubeculosum* type and *Limnophyes* occur on all sampled islands except for Flores and Corvo. However, the diatoms comprised many taxa that occupy most of the islands, with no obvious consistent pattern in average dissimilarities between them. Astorga et al. (2012) suggested that stream diatom communities display strong species sorting over a much broader spatial scale than most macroorganisms

because in diatoms sufficient long-distance dispersal is coupled with extremely fast population growth rates, allowing establishment whenever environmental conditions are suitable. Since island size, age, and proximity to nearby source populations also affect the dispersal and colonization of Azorean organisms (e.g. Borges & Brown, 1999; Borges & Hortal, 2009), further studies are required.

Conclusion

This work presents the first in-depth study that explored the distribution of subfossil diatom and chironomid assemblages in lakes surface sediments from oceanic islands in the North Atlantic. The low diversity of subfossil diatom and chironomid assemblages in Azorean lakes sediments relative to that of continental lakes was similar to that observed on other oceanic islands. These biotic assemblages exhibited different spatial patterns of distribution both within and between the islands of the Azorean archipelago. Diatom assemblages exhibited distinct distribution patterns across different lake depth groups, the shallow lakes assemblages being dominated by benthic diatoms while the planktonic forms predominated in the deep lakes. By contrast, the chironomid assemblages did not present such significant differences between shallow and deep lakes. Their distribution was more influenced by geographic variables, such as latitude and longitude. However, the distribution patterns found indicate that local and regional filters play a key role in shaping the communities across lakes and islands for both organism groups, and that assemblage structure cannot be explained by environmental factors alone. By determining the principal environmental variables that shape diatom and chironomid species distributions, it will be possible to develop inference models for paleoenvironmental reconstructions based on these taxonomic groups. This study clearly shows that the diatom species assemblages differed mainly in the proportion of planktonic versus benthic

diatoms along the lake depth gradient, which indicates the high suitability of using benthic to planktonic indices in paleoreconstructions for similar geographies. The inference models will be applied in studies of lake trophic status, and past climatic trends, allowing the reconstruction of the ecological evolution of lakes in the Azores, to know their pre-impact reference conditions, to define the present human stressors on these ecosystems, and to compare them with the previous pre-impact state. Furthermore, a systematic monitoring of these habitat and biota should be carried out to provide additional information, which would be convenient to improve the lake management for sustainable development and ensure the lakes ecosystem functioning and services.

Acknowledgments

Part of this study was financed by the Fundo Regional da Ciência e Tecnologia (M3.1.7/F/009/2011) and the PaleoNAO project of the Spanish Ministry of Education (CGL2010-15767). We thank the Freshwater Ecology Group from the University of the Azores for all the help in field and laboratory work. The surveys performed comply with the current laws of Portugal.

References

Allan, J. D., 2004. Landscapes and riverscapes: the influence of land use on stream ecosystems. *Annual Review of Ecology and Systematics* 35: 257–284.

Anderson, M. J., R. N. Gorley & K. R. Clarke, 2008. PERMANOVA? for PRIMER: Guide to Software and Statistical Methods. PRIMER-E, Plymouth.

Andrade, C., R. M. Trigo, M. C. Freitas, M. C. Gallego, P. Borges & A. M. Ramos, 2008. Comparing historic records of storm frequency and the North Atlantic Oscillation (NAO) chronology for the Azores region. *The Holocene* 18: 745–754.

Antoniades, D., M. V. Douglas & J. Smol, 2005. Quantitative estimates of recent environmental changes in the Canadian High Arctic inferred from diatoms in lake and pond sediments. *Journal of Paleolimnology* 33: 349–360.

Antunes, P. C. P., 2004. Lagos vulcânicos dos Açores: caracterização geoquímica e Monitorização vulcanológica. Departamento de Geociências, Universidade dos Açores, London: 132.

APHA, 1998. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington DC.

Astorga, A., J. Oksanen, M. Luoto, J. Soinenen, R. Virtanen & T. Muotka, 2012. Distance decay of similarity in freshwater communities: do macro- and microorganisms follow the same rules? *Global Ecology and Biogeography* 21: 365–375.

Azevedo, E. B., 1996. Modelação do clima Insular à Escala Local. Universidade dos Açores, Modelo CIELO aplicado à Ilha Terceira: 247 pp.

Azevedo, E. B., L. S. Pereira & B. Itier, 1998. Modelling the local climate in islands environments. Orographic clouds cover. In Schemenauer, R. S. & H. Bridman (eds), First International Conference on Fog and Fog Collection. IDRC, Ottawa, Canada: 433–436.

Azevedo, E. B., L. S. Pereira & B. Itier, 1999a. Modelling the local climate in islands environments: water balance applications. *Agriculture Water Management* 40: 393–403.

Azevedo, E. B., L. S. Pereira & B. Itier, 1999b. Simulation of local climate in islands environments using a GIS integrated model. In Musy, A., L. S. Pereira & M. Fritsch (eds), Emerging Technologies for Sustainable Land Use and Water Management (EnviroWater99). Lausanne, Switzerland.

Battarbee, R., V. J. Jones, R. J. Flower, N. G. Cameron, H. Bennion, L. Carvalho & S. Juggins, 2001. Diatoms. In Smol, J. P., J. H. B. Birks & W. M. Last (eds), Tracking Environmental Change Using Lake Sediments. Kluwer, Dordrecht.

Battarbee, R. W., D. T. Monteith, S. Juggins, C. D. Evans, A. Jenkins & G. L. Simpson, 2005. Reconstructing pre-acidification pH for an acidified Scottish loch: a comparison of palaeolimnological and modelling approaches. *Environmental Pollution* 137: 135–149.

Bigler, C., O. Heiri, R. Krskova, A. F. Lotter & M. Sturm, 2006. Distribution of diatoms, chironomids and cladocera in surface sediments of thirty mountain lakes in southeastern Switzerland. *Aquatic Sciences* 68: 154–171.

Bigler, C., L. von Gunten, A. F. Lotter, S. Hausmann, A. Blass, C. Ohlendorf & M. Sturm, 2007.

- Quantifying human-induced eutrophication in Swiss mountain lakes since AD 1800 using diatoms. *Holocene* 17: 1141–1154.
- Bilton, D. T., J. R. Freeland & B. Okamura, 2001. Dispersal in freshwater invertebrates. *Annual Review of Ecology and Systematics* 32: 159–181.
- Birks, H. J. B., 2012. Overview of numerical methods in palaeolimnology. In Birks, H. J. B., A. F. Lotter, S. Juggins & J. P. Smol (eds), *Tracking Environmental Change Using Lake Sediments, Vol. 5., Data Handling and Numerical Technique* Springer, Dordrecht: 19–92.
- Borges, P. A. V. & V. K. Brown, 1999. Effect of island geological age on the arthropod species richness of Azorean pastures. *Biological Journal of the Linnean Society* 66: 373–410.
- Borges, P. A. V. & J. Hortal, 2009. Time, area and isolation: factors driving the diversification of Azorean arthropods. *Journal of Biogeography* 36: 178–191.
- Braak, C. J. F. T. & P. Smilauer, 2012. *Canoco Reference Manual and User's Guide: Software for Ordination (Version 5.0)*. Microcomputer Power, Ithaca, New York: 496pp.
- Brasher, A. M. D., R. H. Wolff & C. D. Luton, 2004. Associations Among Land Use, Habitat Characteristics, and Invertebrate Community Structure in Nine Streams on the Island of Oahu, Hawaii, 1999–2001. U.S. Geological Survey Water-Resources Investigations Report 03-4256, Denver: 47pp.
- Brooks, S. J., P. G. Langdon & O. Heiri, 2007. The Identification and Use of Palaeartic Chironomidae Larvae in Palaeoecology. *Quaternary Research Association*, London: vi + 276pp.
- Buchaca, T., T. Skov, S. Amsinck, V. Gonçalves, J. Azevedo, Tr. Andersen & E. Jeppesen, 2011. Rapid ecological shift following piscivorous fish introduction to increasingly eutrophic and warmer Lake Furnas (Azores Archipelago, Portugal): a paleoecological approach. *Ecosystems* 14: 458–477.
- Camburn, K. E. & D. F. Charles, 2000. Diatoms of low-alkalinity lakes in the Northeastern United States. *The Academy of Natural Sciences of Philadelphia*, Philadelphia.
- Capers, R. S., R. Selsky & G. J. Bugbee, 2010. The relative importance of local conditions and regional processes in structuring aquatic plant communities. *Freshwater Biology* 55: 952–966.
- Chen, J., F. Chen, E. Zhang, S. Brooks, A. Zhou & J. Zhang, 2009. A 1000-year chironomid-based salinity reconstruction from varved sediments of Suga Lake, Qaidam Basin, arid Northwest China, and its palaeoclimatic significance. *Chinese Science Bulletin* 54: 3749–3759.
- Clarke, K. R. & R. N. Gorley, 2006. *PRIMER v6: user manual/ tutorial*. PRIMER-E, Plymouth.
- Clarke, K. R. & R. H. Green, 1988. Statistical design and analysis for a 'biological effects' study. *Marine Ecology Progress Series* 46: 213–226.
- Clarke, K. R. & R. M. Warwick, 2001. A further biodiversity index applicable to species lists: variation in taxonomic distinctness. *Marine Ecology Progress Series* 216: 265–278.
- Connor, S. E., J. F. N. van Leeuwen, T. M. Rittenour, W. O. van der Knaap, B. Ammann & S. Björck, 2012. The ecological impact of oceanic island colonization – a palaeoecological perspective from the Azores. *Journal of Biogeography* 39: 1007–1023.
- Constância, J. P., T. J. Braga, J. C. Nunes, E. Machado & L. Silva, 2000. Lagoas e Lagoeiros da Ilha de São Miguel. *Amigos dos Açores – Associação Ecológica*, Ponta Delgada. Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B.
- Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton & M. van den Belt, 1997. The value of the world's ecosystem services and natural capital. *Nature* 387: 253–260.
- Covich, A. P., 2009. Freshwater ecology. In Gillespie, R. G. & D. A. Clague (eds), *Encyclopaedia of Islands*. University of California Press, Berkeley: 343–347.
- Cowie, R. H. & S. H. Brenden, 2006. Dispersal is fundamental to biogeography and the evolution of biodiversity on oceanic islands. *Journal of Biogeography* 33: 193–198.
- Cranston, P. S., 1982. A key to the larvae of British Orthocladinae (Chironomidae). *Freshwater Biological Association, Scientific Publication* 45: 1–152.
- Cruz, J. V., P. Antunes, C. Amaral, Z. França & J. C. Nunes, 2006. Volcanic lakes of the Azores archipelago (Portugal): geological setting and geochemical characterization. *Journal of Volcanology and Geothermal Research* 156: 135–157.

- Cruz, J. V., D. Pacheco, R. Coutinho, R. Cymbron, S. Mendes, P. Antunes, J. Fontiela & P. Freire, 2010. Chemical monitoring of river water bodies in an EU outermost region: examples from the Azores archipelago (Portugal). *Journal of Environmental Monitoring* 12: 2216–2225.
- Cumming, B. F., S. E. Wilson, R. I. Hall & J. P. Smol, 1995. Diatoms from British Columbia (Canada) Lakes and Their Relationship to Salinity, Nutrients and Other Limnological Variables. *Bibliotheca Diatomologica*, vol. 31. J. Cramer, Berlin.
- Dell'Uomo, A., 2004. Índice diatomico di eutrofizzazione/polluzione (EPI-D) nel monitoraggio delle acque correnti. Linee guida. Agenzia per la protezione dell'ambiente e per i servizi tecnici. Centro Tematico Nazionale - Acque Interne e Marino Costiere, Firenze.
- Detenbeck, N., D. Taylor, A. Lima & C. Hagley, 1996. Temporal and spatial variability in water quality of wetlands in the Minneapolis/St. Paul, MN metropolitan area: implications for monitoring strategies and designs. *Environmental Monitoring and Assessment* 40: 11–40.
- Engels, S. & L. C. Cwynar, 2011. Changes in fossil chironomid remains along a depth gradient: evidence for common faunal thresholds within lakes. *Hydrobiologia* 665: 15–38.
- European-Parliament, 2000. Directive 2000/60/EC of the European Parliament and of the council of 23 October 2000 establishing a framework for community action in the field of water policy. *OJEC* 327: 1–73.
- Feld, C. K. & D. Hering, 2007. Community structure or function: effects of environmental stress on benthic macroinvertebrates at different spatial scales. *Freshwater Biology* 52: 1380–1399.
- Ferreira, D. B., 1980. Contribution à l'étude des ventes et de l'humidité dans les îles centrales de l'archipel des Açores. Centro de Estudos Geográficos, Lisboa.
- Flower, R. J., M. Kernan, P. E. Noon & V. J. Jones, 2012. On the factors affecting distributions of freshwater diatom species in a remote South Atlantic archipelago. *European Journal of Phycology* 47: 291–309.
- França, Z., J. V. Cruz, J. C. Nunes & V. Forjaz, 2003. Geologia dos Açores: uma perspectiva actual. *Açoreana* 10: 11–140.
- Francis, D. R., A. P. Wolfe, I. R. Walker & G. H. Miller, 2006. Interglacial and Holocene temperature reconstructions based on midge remains in sediments of two lakes from Baffin Island, Nunavut, Arctic Canada. *Palaeogeography, Palaeoclimatology, Palaeoecology* 236: 107–124.
- Germain, H., 1981. Flore des Diatomées, Diatomophycées: Eaux Douces et Saumâtres du Massif Armoricaïn et des Contrées Voisines d'Europe Occidentale. Nouvelle des Éditions Boubée, Paris.
- Gonçalves, V. M. C., 2008. Contribuição para o estudo da qualidade ecológica das lagoas dos Açores - Fitoplâncton e diatomáceas bentónicas. Departamento de Biologia, Universidade dos Açores, Ponta Delgada: 343.
- Gonçalves, V., P. Raposeiro, A. C. Costa, H. Marques, V. Malhão, J. Micael & A. Cunha, 2008. Caracterização Ecológica das Massas de Água Interiores das Ilhas de São Miguel e Santa Maria da Região Autónoma dos Açores. CCPA, Departamento de Biologia, Universidade dos Açores, Ponta Delgada: 117pp.
- Gonçalves, V., A. Costa, P. Raposeiro, H. Marques, A. Cunha, J. Ramos, A. Cruz & C. Pereira, 2009. Caracterização Biológica das Massas de Água Interiores das Ilhas de Faial e Pico. CCPA/Departamento de Biologia, Universidade dos Açores, Ponta Delgada: 77pp.
- Göthe, E., D. G. Angeler, S. Gottschalk, S. Löfgren & L. Sandin, 2013. The influence of environmental, biotic and spatial factors on diatom metacommunity structure in Swedish headwater streams. *PLoS ONE* 8: e72237.
- Hall, R. I. & J. P. Smol, 1992. A weighted—averaging regression and calibration model for inferring total phosphorus concentration from diatoms in British Columbia (Canada) lakes. *Freshwater Biology* 27: 417–434.
- Heiri, O., 2004. Within-lake variability of subfossil chironomid assemblages in shallow Norwegian lakes. *Journal of Paleolimnology* 32: 67–84.
- Holmes, N., P. G. Langdon & C. J. Caseldine, 2009. Subfossil chironomid variability in surface sediment samples from Icelandic lakes: implications for the development and use of training sets. *Journal of Paleolimnology* 42: 281–295.
- Hughes, S. & B. Malmqvist, 2005. Atlantic islands freshwater ecosystems: challenges and considerations following the EU Water

- Framework Directive. *Hydrobiologia* 544: 289–297.
- Hurrell, J. W., Y. Kushnir, G. Ottersen & M. Visbeck, 2003. An overview of the North Atlantic Oscillation. In Hurrell, J. W. (ed.), *The North Atlantic Oscillation: Climatic Significance and Environmental Impact*. Geophysical Monograph, Vol. 134. American Geophysical Union, Washington: 1–35.
- Hyodo, F., N. Tsugeki, J.-I. Azuma, J. Urabe, M. Nakanishi & E. Wada, 2008. Changes in stable isotopes, lignin-derived phenols, and fossil pigments in sediments of Lake Biwa, Japan: implications for anthropogenic effects over the last 100 years. *Science of the Total Environment* 403: 139–147.
- IPQ, 1997. Qualidade da água. Doseamento da clorofila a e dos feopigmentos por espectrofotometria de absorção molecular. Método de extracção com acetona. NP 4327/1996. Instituto Português da Qualidade, Monte da Caparica.
- Juggins, S., 2003. C2 User Guide. Software for Ecological and Palaeoecological Data Analysis and Visualisation, Version 1.5. Newcastle University, Newcastle.
- Karst-Riddoch, T. L., H. J. Malmquist & J. P. Smol, 2009. Relationships between freshwater sedimentary diatoms and environmental variables in Subarctic Icelandic lakes. *Archiv fur Hydrobiologie* 175: 1–28.
- Krammer, K., 2000. The Genus *Pinnularia*. Diatoms of Europe, Ruggel.
- Krammer, K. & H. Lange-Bertalot, 1985. Naviculaceae. *Bibliotheca Diatomologica*, Cramer, Berlin.
- Krammer, K. & H. Lange-Bertalot, 1986. Bacillariophyceae. 1. Naviculaceae. *Susswasserflora von Mitteleuropa*. Gustav Fisher Verlag, Jena.
- Krammer, K. & H. Lange-Bertalot, 1988. Bacillariophyceae. 2. Bacillareaceae, Epithemiaceae, Surirellaceae. *Susswasserflora von Mitteleuropa*. Gustav Fisher Verlag, Stuttgart.
- Krammer, K. & H. Lange-Bertalot, 1991a. Bacillariophyceae. 3. Centrales, Fragilariaceae, Eunotiaceae. *Susswasserflora von Mitteleuropa*. Gustav Fisher Verlag, Stuttgart.
- Krammer, K. & H. Lange-Bertalot, 1991b. Bacillariophyceae. 4. Achnantheaceae. *Susswasserflora von Mitteleuropa*. Gustav Fisher Verlag, Stuttgart.
- Krammer, K. & H. Lange-Bertalot, 2000. Bacillariophyceae. 5. English and French translation of the keys. *Susswasserflora von Mitteleuropa*. Gustav Fisher Verlag, Stuttgart.
- Langdon, P., N. Holmes & C. Caseldine, 2008. Environmental controls on modern chironomid faunas from NW Iceland and implications for reconstructing climate change. *Journal of Paleolimnology* 40: 273–293.
- Lecointe, C., M. Coste & J. Prygiel, 1993. “Omnidia”: software for taxonomy, calculation of diatom indices and inventories management. *Hydrobiologia* 269–270: 509–513.
- Leps, J. & P. Smilauer, 2003. *Multivariate Analysis of Ecological Data Using CANOCO*. Cambridge University Press, Cambridge.
- Lim, D. S., M. V. Douglas & J. Smol, 2001. Diatoms and their relationship to environmental variables from lakes and ponds on Bathurst Island, Nunavut, Canadian High Arctic. *Hydrobiologia* 450: 215–230.
- Lorenzen, L. J., 1967. Determination of chlorophyll and pheo-pigments: spectrophotometric equations. *Limnology and Oceanography* 12: 343–346.
- Malmqvist, B., A. N. Nilsson, M. Baez, P. D. Armitage & J. Blackburn, 1993. Stream macroinvertebrate communities in the island of Tenerife. *Archiv fur Hydrobiologie* 128: 209–235.
- Marchetto, A., A. Lami, S. Musazzi, J. Massaferrò, L. Langone & P. Guilizzoni, 2004. Lake Maggiore (N. Italy) trophic history: fossil diatom, plant pigments, and chironomids, and comparison with long-term limnological data. *Quaternary International* 113: 97–110.
- McArdle, B. H. & M. J. Anderson, 2001. Fitting multivariate models to community data: a comment on distance-based redundancy analysis. *Ecology* 82: 290–297.
- Millet, L., C. Giguet-Covex, V. Verneaux, J.-C. Druart, T. Adate & F. Arnaud, 2010. Reconstruction of the recent history of a large deep prealpine lake (Lake Bourget, France) using subfossil chironomids, diatoms, and organic matter analysis: towards the definition of a lake-specific reference state. *Journal of Paleolimnology* 44: 963–978.

- Nichols, J. E., M. Walcott, R. Bradley, J. Pilcher & Y. Huang, 2009. Quantitative assessment of precipitation seasonality and summer surface wetness using ombrotrophic sediments from an Arctic Norwegian peatland. *Quaternary Research* 72: 443–451.
- Nürnberg, G. K., 1996. Trophic state of clear and colored, soft- and hardwater lakes with special consideration of nutrients, anoxia, phytoplankton and fish. *Journal of Lake and Reservoir Management* 12: 432–447.
- Oliver, D. R. & M. E. Roussel, 1983. The Genera of Larval Midges of Canada. Diptera: Chironomidae. In *The Insects and Arachnids of Canada*. Biosystematics Research Institute Ottawa, Ontario: 263.
- Patrick, R. & C. W. Reimer, 1966. *The Diatoms of the United States, Exclusive of Alaska and Hawaii*. Livingston Company, Philadelphia.
- Pinder, L. C. V. & F. Reiss, 1983. The larvae of Chironominae (Diptera: Chironomidae) of the Holarctic region. In Wiederholm, T. (ed.), *Chironomidae of Holarctic Region – Keys and Diagnoses (Part 1 – Larvae)*. Entomologica Scandinavica Supplements, Lund: 293–436.
- Porteiro, J. M. M., 2000. Lagoas dos Açores. Elementos de Suporte ao Planeamento Integrado. Universidade dos Açores, Ponta Delgada.
- Raposeiro, P. M. & A. C. Costa, 2009. Benthic macroinvertebrate based indices for assessing the ecological status of freshwaters on oceanic islands. *ARQUIPELAGO – Life and Marine Sciences* 26: 15–24.
- Raposeiro, P. M., S. J. Hughes & A. C. Costa, 2009. Chironomidae (Diptera: Insecta) in oceanic islands: new records for the Azores and biogeographic notes. *Annales de Limnologie – International Journal of Limnology* 45: 59–67.
- Raposeiro, P. M., A. M. Cruz, S. J. Hughes & A. C. Costa, 2012. Azorean freshwater invertebrates: status, threats and biogeographic notes. *Limnetica* 31: 13–22.
- Raposeiro, P. M., S. H. Hughes & A. C. Costa, 2013. Environmental drivers – spatial and temporal variation of macroinvertebrate communities in island streams: the case of the Azores Archipelago. *Archiv für Hydrobiologie* 182: 337–350.
- Renberg, I., 1990. A procedure for preparing large sets of diatom slides from sediment cores. *Journal of Paleolimnology* 4: 87–90.
- Rieradevall, M. & S. J. Brooks, 2001. An identification guide to subfossil Tanypodinae larvae (Insecta: Diptera: Chironomidae) based on cephalic setation. *Journal of Palaeolimnology* 25: 81–99.
- Shinneman, A. L. C., D. M. Bennett, S. C. Fritz, J. Schmieder, D. R. Engstrom, A. Efting & J. Holz, 2010. Inferring lake depth using diatom assemblages in the shallow, seasonally variable lakes of the Nebraska Sand Hills (USA): calibration, validation, and application of a 69-lake training set. *Journal of Paleolimnology* 44: 443–464.
- Skov, T., T. Buchaca, S. Amsinck, F. Landkildehus, B. Odgaard, J. Azevedo, V. Gonçalves, P. Raposeiro, T. Andersen & E. Jeppesen, 2010. Using invertebrate remains and pigments in the sediment to infer changes in trophic structure after fish introduction in Lake Fogo: a crater lake in the Azores. *Hydrobiologia* 654: 13–25.
- Smith, V. H., G. D. Tilman & J. C. Nekola, 1999. Eutrophication: impacts of excessive nutrient inputs on freshwater, marine, and terrestrial ecosystems. *Environmental Pollution* 100: 179–196.
- Smol, J. P., 2008. *Pollution of Lakes and Rivers: A Paleoenvironmental Perspective*. Blackwell Publishing, Oxford: 383.
- Vanormelingen, P., E. Verleyen & W. Vyverman, 2008. The diversity and distribution of diatoms: from cosmopolitanism to narrow endemism. *Biodiversity Conservation* 17: 393–405.
- Verbruggen, F., O. Heiri, J. J. Meriläinen & A. F. Lotter, 2011. Subfossil chironomid assemblages in deep, stratified European lakes: relationships with temperature, trophic state and oxygen. *Freshwater Biology* 56: 407–423.
- Vyverman, W., E. Verleyen, K. Sabbe, K. Vanhoutte, M. Sterken, D. A. Hodgson, D. G. Mann, S. Juggins, B. Van de Vijver, V. Jones, R. J. Flower, D. Roberts, V. A. Chepurnov, C. Kilroy, P. Vanormelingen & A. De Wever, 2007. Historical processes constrain patterns in global diatom diversity. *Ecology* 88: 1924–1931.
- Wang, Q., X. Yang, P. B. Hamilton & E. Zhang, 2012. Linking spatial distributions of sediment diatom assemblages with hydrological depth profiles in a plateau deep-water lake system of subtropical China. *Fottea* 12: 59–73.

Wetzel, R. G., 2001. *Limnology. Lake and River Ecosystems*. Academic Press, San Diego: 1006.

Williams, J. J., S. J. Brooks & W. D. Gosling, 2012. Response of chironomids to late Pleistocene and Holocene environmental change in the eastern Bolivian Andes. *Journal of Paleolimnology* 48: 485–501.

Wolin, J. A. & J. R. Stone, 2010. Diatoms as indicators of water-level change in freshwater lakes. In Smol, J. P. & E. F. Stoermer (eds), *The Diatoms: Applications for the Environmental and Earth Sciences*. Cambridge University Press, Cambridge: 174–185.

Biogeography and lake morphometry drive diatom and chironomid assemblages' composition in lacustrine surface sediments of oceanic islands

Hydrobiologia

Cátia Lúcio Pereira^{1*}, Pedro Miguel Raposeiro¹, Ana Cristina Costa¹, Roberto Bao², Santiago Giralt³ and Vítor Gonçalves¹

¹CIBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, InBIO Laboratório Associado, Pólo dos Açores – Departamento de Biologia da Universidade dos Açores, 9501-801 Ponta Delgada, Portugal

²Faculty of Sciences, University of A Coruña, Campus da Zapateira s/n, 15071 A Coruña, Spain

³Institute of Earth Sciences Jaume Almera CSIC, Sedimentary Geology, Lluís Solé I Sabaris s/n, E-08028 Barcelona, Spain

*email: catiaalpereira@gmail.com

Online Resource 1

Table 1 Location and main characteristics (spatial, hydromorphological, physicochemical and impacte) of the studied Azorean lakes

Lake Full Name	Typology	Spatial Variables		Hydromorphological Variables					Physicochemical Variables										Impacte Variables				
		Lat (UTM)	Long (UTM)	Alt (m)	LA (km ²)	Zmax (m)	Temp (°C)	July T (°C)	pH	Cond (µS/cm)	Alk (CaCO ₃ /L)	TP (µg P/L)	TN (mg N/L)	N _{Ki} (mg N/L)	NO ₃ (mg NO ₃ /L)	NO ₂ (mg NO ₂ /L)	TN/TP	Si (mg SiO ₂ /L)	Z _{SD} (m)	Chla (µg/L)	%Agr (%)	%Oth (%)	%Flo (%)
Areiro	Shallow	4180720.06	638559.61	630	0.0045	2.70	11.10	16.60	5.60	39.80	4.00	9.00	0.15	0.10	0.15	0.05000	0.0167	2.80	2.70	1.65	0.00	0.00	100.00
Caldeirão Norte	Shallow	4186995.33	609962.58	770	0.0018	0.40	11.20	15.00	5.90	32.80	3.00	6.00	0.15	0.10	0.15	0.05000	0.0250	1.05	0.40	1.45	0.00	20.00	80.00
Caldeirão Sul	Shallow	4186942.06	609997.65	770	0.0039	0.80	11.10	15.00	7.00	37.40	4.00	11.00	0.15	0.10	0.15	0.05000	0.0136	1.05	0.80	8.24	0.00	5.88	94.12
Canário	Shallow	4188336.28	609147.63	750	0.0178	2.30	14.50	14.60	6.46	37.83	3.13	22.75	0.15	0.13	0.03	0.00005	0.0066	0.58	1.28	11.40	0.00	2.80	97.20
Canas	Shallow	4185821.54	612069.25	570	0.0019	2.40	22.80	16.60	6.30	34.80	7.00	16.00	0.30	0.30	0.20	0.05000	0.0188	1.05	2.40	2.71	75.00	0.00	25.00
Carvão	Shallow	4187053.71	610729.10	680	0.0115	0.40	19.80	15.50	7.50	37.60	12.00	15.00	0.15	0.10	0.15	0.05000	0.0100	6.60	0.40	1.74	0.00	26.44	73.56
Congro	Deep	4179982.69	640241.90	420	0.0370	17.73	16.30	18.00	8.47	91.70	22.50	31.00	0.43	0.23	0.17	0.00005	0.0137	9.50	2.13	30.12	25.74	36.14	38.12
Empadadas Norte	Shallow	4187226.07	610176.10	740	0.0175	3.30	14.10	15.00	6.62	33.88	3.63	19.50	0.16	0.13	0.03	0.00005	0.0083	1.27	1.68	11.17	0.00	3.90	96.10
Empadadas Sul	Shallow	4187091.70	610274.94	750	0.0048	2.45	13.70	15.20	6.95	49.40	7.25	18.25	0.19	0.13	0.04	0.00005	0.0103	1.41	2.08	4.89	0.00	2.90	97.10
Fogo	Deep	4180740.35	633514.96	574	1.4366	24.20	12.63	16.80	7.59	49.35	7.25	8.63	0.18	0.15	0.03	0.00005	0.0203	2.20	3.63	4.08	0.00	5.13	94.87
Fogo 2	Shallow	4181112.88	633673.39	574	0.0481	1.98	12.00	17.00	7.00	27.30	3.00	32.00	0.15	0.10	0.15	0.05000	0.0047	2.60	1.00	23.54	0.00	5.13	94.87
Furnas	Deep	4180143.86	647150.83	280	1.9257	11.50	17.13	19.20	8.22	128.75	48.00	60.25	0.43	0.33	0.05	0.00001	0.0071	15.60	0.85	38.54	44.68	4.83	51.03
Pau-Pique	Shallow	4187922.20	610393.20	690	0.0025	4.50	11.10	16.20	6.80	36.10	4.00	380.00	0.15	0.10	0.15	0.05000	0.0004	0.70	1.50	9.93	0.00	0.00	100.00
Peixe	Shallow	4186450.13	611231.69	620	0.0035	1.50	22.70	16.40	7.20	60.40	23.00	40.00	0.15	0.10	0.15	0.05000	0.0038	2.10	0.70	17.16	9.84	4.92	85.25
Pico d'El Rei 1	Shallow	4181900.00	642085.00	627	0.0010	1.10	10.90	15.80	8.85	68.30	19.00	251.00	0.80	0.80	0.15	0.05000	0.0032	4.40	0.50	205.94	0.00	0.00	100.00
Pico d'El Rei 2	Shallow	4181654.00	641700.00	648	0.0014	0.60	10.00	15.40	6.43	47.10	13.00	168.00	0.15	0.10	0.15	0.05000	0.0009	4.40	0.60	58.04	0.00	0.00	100.00
Pico d'El Rei 3	Shallow	4181849.65	641566.88	593	0.0041	1.00	10.20	16.00	7.55	55.80	17.00	385.00	0.15	0.10	0.15	0.05000	0.0004	5.10	0.30	465.43	0.00	0.00	100.00
Rasa da Serra Devassa	Shallow	4187131.44	609876.37	765	0.0331	0.80	10.83	14.80	6.65	46.73	2.50	7.13	0.16	0.13	0.03	0.00005	0.0228	1.05	0.80	2.89	0.00	3.36	96.64
Rasa das Sete Cidades	Shallow	4189125.49	607359.61	545	0.0393	4.53	14.73	16.40	6.07	34.15	2.50	2.50	0.16	0.13	0.03	0.00005	0.0650	0.39	3.98	2.15	2.00	0.00	98.00
Santiago	Deep	4189551.18	607989.45	360	0.2535	28.75	15.60	18.00	8.50	118.75	33.75	21.50	0.19	0.13	0.05	0.00005	0.0087	2.73	2.58	7.70	0.00	0.00	100.00
São Brás	Shallow	4184056.94	640013.62	610	0.0582	2.05	15.33	16.20	6.91	35.85	6.25	126.75	0.55	0.53	0.03	0.00005	0.0043	1.78	0.40	33.35	50.00	3.85	46.15
Azul	Deep	4192417.68	608243.52	260	3.5868	25.35	16.48	18.70	7.83	94.55	23.25	9.50	0.19	0.15	0.03	0.00005	0.0197	0.70	2.20	5.35	42.34	7.56	52.36
Verde	Deep	4189071.90	606553.94	260	0.8563	23.50	15.78	19.20	8.61	118.50	32.75	28.50	0.43	0.33	0.06	0.00005	0.0149	1.33	1.25	26.19	18.09	2.04	80.06
Negro	Shallow	4287768.57	476631.37	540	0.0044	1.20	11.10	18.20	5.93	40.30	4.00	32.00	0.15	0.10	0.15	0.05000	0.0047	1.05	1.20	14.16	33.96	2.83	63.21
Lagoínha da Serreta	Shallow	4289038.42	471211.26	777	0.0045	1.60	10.80	20.40	5.41	40.60	1.50	11.00	0.15	0.10	0.15	0.05000	0.0136	2.80	1.60	3.09	0.00	0.00	100.00
Vale Fundo	Shallow	4287629.87	483224.69	660	0.0005	1.40	11.80	16.40	6.02	51.10	11.00	296.00	0.15	0.10	0.40	0.05000	0.0005	3.60	0.40	88.56	0.00	0.00	100.00
Caiado	Shallow	4257155.56	390879.19	810	0.0545	4.60	13.73	16.60	6.50	28.53	3.75	12.67	0.20	0.18	0.04	0.01217	0.0158	1.33	1.53	2.17	64.39	7.58	28.03

Table 1 Location and main characteristics (spatial, hydromorphological, physicochemical and impacte) of the studied Azorean lakes (continuation)

Lake Full Name	Typology	Spatial Variables		Hydromorphological Variables			Physicochemical Variables											Impacte Variables					
		Lat (UTM)	Long (UTM)	Alt (m)	LA (km ²)	Zmax (m)	Temp (°C)	July T (°C)	pH	Cond (µS/cm)	Alk (CaCO ₃ /L)	TP (µg P/L)	TN (mg N/L)	N _{Ki} (mg N/L)	NO ₃ (mg NO ₃ /L)	NO ₂ (mg NO ₂ /L)	TN/TP	Si (mg SiO ₂ /L)	Z _{SD} (m)	Chla (µg/L)	%Agr (%)	%Oth (%)	%Flo (%)
Capitão	Shallow	4260771.00	384929.00	790	0.0266	4.03	13.68	16.10	6.30	28.63	3.38	31.75	0.26	0.21	0.03	0.01217	0.0083	0.88	0.53	25.40	79.19	2.01	18.79
Landroal	Shallow	4257351.47	389402.63	790	0.0064	2.40	13.20	17.20	6.82	32.80	5.00	14.00	0.15	0.10	0.10	0.05000	0.0107	2.10	2.40	4.12	58.70	2.17	39.13
Paul	Shallow	4253986.85	392391.68	790	0.0166	2.90	15.73	16.50	6.06	28.67	3.67	20.50	0.20	0.17	0.03	0.01319	0.0098	1.05	2.00	1.44	16.04	0.09	83.87
Peixinho	Shallow	4254694.99	397515.26	870	0.0133	7.80	13.83	15.80	6.92	31.88	7.75	33.75	0.63	0.55	0.08	0.01217	0.0185	3.15	0.30	49.43	99.31	0.69	0.00
Rosada	Shallow	4254495.18	396507.34	900	0.0114	7.10	14.20	15.60	6.90	29.60	3.25	12.50	0.20	0.18	0.03	0.01217	0.0160	0.70	1.57	3.13	98.90	1.10	0.00
Lagoinha do Paul	Shallow	4254080.06	403566.06	510	0.0011	1.70	16.20	18.20	6.48	40.40	7.00	81.00	0.20	0.20	0.15	0.05000	0.0025	1.60	1.70	30.10	92.00	0.00	8.00
Branca	Shallow	4368098.78	652638.77	570	0.0475	1.60	13.60	17.60	6.02	48.00	5.00	11.00	0.15	0.10	0.15	0.05000	0.0136	2.10	1.60	1.03	0.00	0.00	100.00
Comprida	Deep	4367232.41	652998.76	650	0.0544	14.30	14.13	17.80	7.42	71.80	13.50	10.25	0.20	0.18	0.03	0.13694	0.0195	1.25	2.53	1.86	0.00	1.65	98.35
Funda	Deep	4363277.32	653537.56	360	0.3547	31.90	16.33	19.20	8.71	100.38	34.75	28.75	0.28	0.18	0.09	0.47927	0.0096	7.95	0.84	53.35	15.20	0.04	84.76
Lomba	Deep	4365545.02	655906.77	650	0.0205	15.27	14.53	16.30	7.34	52.48	7.00	9.63	0.18	0.13	0.03	0.13694	0.0182	0.93	2.80	2.41	61.04	20.78	18.18
Negra	Deep	4367314.87	652675.72	530	0.1107	115.00	15.23	17.90	8.33	123.75	39.75	62.25	0.23	0.13	0.09	0.13694	0.0036	12.85	1.75	12.05	0.00	0.00	100.00
Rasa	Deep	4363624.99	652868.90	530	0.1031	16.80	15.50	17.90	6.62	54.43	3.00	7.75	0.18	0.13	0.03	0.02396	0.0226	0.63	2.13	4.92	0.00	3.61	96.39
Caldeirão	Shallow	4397541.94	661871.49	410	0.2307	0.20	14.30	18.70	6.91	75.83	4.50	33.25	0.19	0.15	0.03	0.01369	0.0056	0.21	0.20	7.70	70.38	3.37	26.25
Caldeirão 2	Shallow	4397519.58	662390.83	410	0.0852	2.20	13.80	18.80	6.01	78.20	1.50	94.00	0.90	0.10	3.80	0.05000	0.0096	2.20	1.00	9.58	70.38	3.37	26.25

Biogeography and lake morphometry drive diatom and chironomid assemblages' composition in lacustrine surface sediments of oceanic islands

Hydrobiologia

Cátia Lúcio Pereira^{1*}, Pedro Miguel Raposeiro¹, Ana Cristina Costa¹, Roberto Bao², Santiago Giral³ and Vítor Gonçalves¹

¹CIBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, InBIO Laboratório Associado, Pólo dos Açores – Departamento de Biologia da Universidade dos Açores, 9501-801 Ponta Delgada, Portugal

²Faculty of Sciences, University of A Coruña, Campus da Zapateira s/n, 15071 A Coruña, Spain

³Institute of Earth Sciences Jaume Almera CSIC, Sedimentary Geology, Lluís Solé I Sabaris s/n, E-08028 Barcelona, Spain

*email: catiaalpereira@gmail.com

Online Resource 2 List of diatoms species identified in surface sediment of 41 Azorean lakes and their respective codes.

PHYLUM	CLASS	SUBCLASS	ORDER	FAMILY	SPECIES	TAXA CODE			
Bacillariophyta	Coscinodiscophyceae	Thalassiosirophyceidae	Thalassiosirales	Thalassiosiraceae	<i>Discostella pseudostelligera</i> (Hustedt) Houk & Klee	DPST			
					<i>Discostella woltereckii</i> (Hustedt) Houk & Klee	DWOL			
				Stephanodiscaceae	<i>Cyclotella atomus</i> Hustedt	CATO			
					<i>Cyclotella meneghiniana</i> Kützing	CMEN			
					<i>Cyclotella cf. ocelata</i> Pantocsek	COCE			
					<i>Stephanodiscus hantzschii</i> Grunow	SHAN			
					<i>Stephanodiscus parvus</i> Stoermer & Håkansson	SPAV			
					Coscinodiscophycidae	Aulacoseirales	Aulacoseiraceae	<i>Aulacoseira ambigua</i> (Grunow) Simonsen	AAMB
								<i>Aulacoseira distans</i> (Ehrenberg) Simonsen	AUDI
				<i>Aulacoseira granulata</i> (Ehrenberg) Simonsen				AUGR	
				<i>Aulacoseira nygaardii</i> (Camburn) Camburn & Charles				AUNY	
				Rhizosoleniophycidae	Rhizosoleniales	Rhizosoleniaceae	<i>Urosolenia eriensis</i> F. E. Round & R.M. Crawford	UERI	
				Fragilariophyceae	Fragilariophycidae	Fragilariales	Fragilariaceae	<i>Asterionella formosa</i> Hassall	AFOR
								<i>Diatoma mesodon</i> (Ehrenberg) Kützing	SMES
								<i>Fragilaria capucina</i> Desmazieres	FCAP
								<i>Fragilaria capucina</i> var. <i>distans</i> (Grunow) Boye-Petersen	FCDI
								<i>Fragilaria capucina</i> var. <i>vauchaeriae</i> (Kützing) Lange-Bertalot	FCVA
								<i>Fragilaria crotonensis</i> Kitton	FCRO
								<i>Fragilaria gracilis</i> Østrup	FGRA
								<i>Fragilaria henryi</i> Lange-Bertalot	FHEN
								<i>Fragilaria radians</i> (Kützing) Williams & Round	FRAD
								<i>Fragilaria rumpens</i> Carlson	FRUM
								<i>Fragilaria cf. tenera</i> (W. Smith) Lange-Bertalot	FTEN
<i>Pseudostaurosira brevistriata</i> (Grunow) Williams & Round	PSBR								
<i>Pseudostaurosira brevistriata</i> var. <i>inflata</i> (Pantocsek) Edlund	PBIF								
<i>Pseudostaurosira parasitica</i> var. <i>subconstricta</i> (Grunow) E. Morales	OOSC								
<i>Pseudostaurosira subsalina</i> (Hustedt) Morales	PSSB								
<i>Pseudostaurosira</i> sp.1	PSST1								
<i>Stauroforma exiguiformis</i> (Lange-Bertalot) Flower, Jones & Round	SEXG								
<i>Staurosira elliptica</i> (Schumann) Williams & Round	SELI								
<i>Staurosira pseudoconstruens</i> (Marciniak) Lange-Bertalot	SPCO								
<i>Staurosira</i> sp. 1	STRS1								
<i>Staurosira</i> sp. 2	STRS2								
<i>Staurosirella pinnata</i> (Ehrenberg) Williams & Round	SPIN								
<i>Ulnaria biceps</i> (Kützing) P. Compère	UBIC								
<i>Ulnaria danica</i> (Kützing) Compère & Bukhtiyarova	UDAN								
<i>Ulnaria delicatissima</i> (Smith) Aboal & Silva	UDEL								
<i>Ulnaria delicatissima</i> var. <i>angustissima</i> (Smith) Aboal & Silva	UDEA								
<i>Ulnaria ulna</i> (Nitzsch) P. Compère	UULN								
<i>Ulnaria ulna</i> var. <i>acus</i> (Kützing) Lange-Bertalot	UUAC								
			Tabellariales					Tabellariaceae	<i>Tabellaria flocculosa</i> morfo. 1 (Roth) Kützing
					<i>Tabellaria flocculosa</i> morfo. 2 (Roth) Kützing	TFLO morfo2			
Bacillariophyceae	Eunotiophycidae	Eunotiales	Eunotiaceae	<i>Eunotia bidentata</i> W.M. Smith	EBID				
				<i>Eunotia bilunaris</i> (Ehrenberg) Mills	EBIL				
				<i>Eunotia exigua</i> (Brebisson ex Kützing) Rabenhorst	EEXI				
				<i>Eunotia implicata</i> Nörpel, Lange-Bertalot & Alles	EIMP				
				<i>Eunotia incisa</i> Gregory	EINC				
				<i>Eunotia intermedia</i> (Krasske) Nörpel & Lange-Bertalot	EUIJ				
				<i>Eunotia paludosa</i> Grunow in Van Heurck	EUPA				
				<i>Eunotia praeurupta</i> Ehrenberg	EPRA				
				<i>Eunotia tetradon</i> (Ehrenberg) Ralfs	ETET				
				Bacillariophycidae	Cymbellales	Cymbellaceae	<i>Cymbella helvetica</i> Kützing	CHEL	
				PHYLUM	CLASS	SUBCLASS	ORDER	FAMILY	SPECIES

		<i>Encyonema gaeumannii</i> (Meister) D.G. Mann	EGAE			
		<i>Encyonema minutum</i> (Hilse) D.G. Mann	ENMI			
		<i>Encyonema neogracile</i> Krammer	ENNG			
		<i>Encyonema perpusillum</i> (A. Cleve) D.G. Mann	ENPE			
		<i>Encyonema silesiacum</i> (Bleisch) D.G. Mann	ENSL			
		<i>Encyonema</i> sp.1	ENCY1			
		<i>Encyonopsis</i> sp.1	ENCP1			
		<i>Placoneis elginensis</i> (Greg) Cox	PELG			
	Gomphonemataceae	<i>Gomphonema clavatum</i> Ehrenberg	GCLA			
		<i>Gomphonema exiguum</i> Kützing	GEXG			
		<i>Gomphonema gracile</i> Ehrenberg	GGRA			
		<i>Gomphonema laticollum</i> Reichardt	GLTC			
		<i>Gomphonema parvulum</i> (Kützing) Kützing	GPAR			
		<i>Gomphonema pumilum</i> (Grunow) Reichardt & Lange-Bertalot	GPUM			
		<i>Gomphonema truncatum</i> Ehrenberg	GTRU			
Achnanthes	Achnantheaceae	<i>Achnanthes lutheri</i> Hustedt	ALUT			
	Cocconeidaceae	<i>Cocconeis placentula</i> Ehrenberg	CPLA			
		<i>Cocconeis</i> sp.1	COCS			
	Achnanthidiaceae	<i>Achnanthidium exiguum</i> (Grunow) Czarnecki	ADEG			
		<i>Achnanthidium minutissimum</i> (Kützing) Czarnecki	ADMI			
		<i>Achnanthidium subatomoides</i> (Hustedt) Monnier, Lange-Bertalot & Ector	ADSO			
		<i>Karayevia carissima</i> (Lange-Bertalot) Bukhtiyarova	KCAR			
		<i>Karayevia clevei</i> (Grunow) Round & Bukhtiyarova	KCLE			
		<i>Karayevia cf. oblongella</i> (Østrup) M.Aboal	KOBB			
		<i>Planothidium delicatulum</i> (Kützing) Round & L. Bukhtiyarova	PTDE			
		<i>Planothidium frequentissimum</i> (Lange-Bertalot) Round & Bukhtiyarova	PLFR			
		<i>Planothidium lanceolatum</i> (Brebisson ex Kützing) Lange-Bertalot	PTLA			
		<i>Planothidium</i> sp.1	PTDS1			
		<i>Psammothidium altaicum</i> (Poretzky) Bukhtiyarova	PALT			
		<i>Rosithidium pusillum</i> (Grunow) Round & Bukhtiyarova	RPUS			
Naviculales	Berkeleyaceae	<i>Parlibellus protracta</i> (Grunow) Witkowski, Lange-Bertalot & Metzeltin	PPRO			
	Cavinulaceae	<i>Cavinula cocconeiformis</i> (Gregory ex Greville) Mann & Stickle	CCOC			
		<i>Cavinula lapidosa</i> (Krasske) Lange-Bertalot	CVLP			
		<i>Cavinula variostrata</i> (Krasske) Mann & Stickle	CVVA			
	Diadesmidaceae	<i>Diadesmis contenta</i> (Grunow ex Van Heurck) Mann	DCOT			
		<i>Diadesmis perpusilla</i> (Grunow) D.G. Mann in Round, Crawford & Mann	DPER			
		<i>Luticola goeppertiana</i> (Bleisch) D.G. Mann	LGOE			
		<i>Luticola mutica</i> (Kützing) D.G. Mann	LMUT			
	Amphipleuraceae	<i>Amphipleura kriegeriana</i> (Krasske) Hustedt	AKRI			
		<i>Frustulia crassinervia</i> (Brebisson) Lange-Bertalot & Krammer	FCRS			
		<i>Frustulia rhomboides</i> (Ehrenberg) De Toni	FRHO			
		<i>Frustulia saxonica</i> Rabenhorst	FSAX			
		<i>Frustulia vulgaris</i> (Thwaites) De Toni	FVUL			
		<i>Frustulia</i> sp.1	FRSP1			
	Brachysiraceae	<i>Brachysira brebissonii</i> Ross in Hartley	BBRE			
		<i>Brachysira neoexilis</i> H.Lange-Bertalot	BNEO			
		<i>Brachysira serians</i> (Brebisson) Round & Mann	BSER			
	Neidiaceae	<i>Neidium affine</i> (Ehrenberg) Pfizer	NEAF			
		<i>Neidium hercynicum</i> Mayer	NEHC			
		<i>Neidium septentrionale</i> Cleve-Euler	NESE			
	Sellaphoraceae	<i>Fallacia tenera</i> (Hustedt) D.G. Mann	FTNR			
		<i>Sellaphora minima</i> (Grunow) Mann	SEMN			
		<i>Sellaphora mutatooides</i> Lange-Bertalot & Metzeltin	SMTO			
		<i>Sellaphora pupula</i> (Kützing) Mereschkowksy	SPUP			
		<i>Sellaphora seminulum</i> (Grunow) D.G.Mann	SSEM			
		<i>Sellaphora</i> sp.1	SELS1			
	Pinnulariaceae	<i>Caloneis bacillum</i> (Grunow) Cleve	CBAC			
		<i>Caloneis hyalina</i> Hustedt	CHYA			
		<i>Caloneis silicula</i> (Ehrenberg) Cleve	CSIL			
		<i>Caloneis tenuis</i> (Gregory) Krammer	CATE			
		<i>Caloneis undulata</i> (Gregory) Krammer	CUDU			
		<i>Caloneis</i> sp.1	CALS1			
		<i>Pinnularia acuminata</i> W. Smith	PACU			
		<i>Pinnularia dubitabilis</i> var. <i>dubitabilis</i>	PDUB			
		<i>Pinnularia hemiptera</i> (Kützing) Rabenhorst	PHEM			
		<i>Pinnularia intermedia</i> (Lagerstedt) Cleve	PITM			
		<i>Pinnularia interrupta</i> W.M. Smith	PINT			
		<i>Pinnularia major</i> (Kützing) Rabenhorst	PMAJ			
PHYLUM	CLASS	SUBCLASS	ORDER	FAMILY	SPECIES	TAXA CODE
					<i>Pinnularia microstauron</i> (Ehrenberg) Cleve	PMIC

				<i>Pinnularia perirrorata</i> Krammer	PPER	
				<i>Pinnularia rhomboelliptica</i> Krammer	PRHE	
				<i>Pinnularia sinistra</i> Krammer	PSIN	
				<i>Pinnularia schoenfelderi</i> Krammer	PSHO	
				<i>Pinnularia subcapitata</i> Gregory	PSCA	
				<i>Pinnularia subgibba</i> Krammer	PSGI	
Diploneidaceae				<i>Diploneis ovalis</i> (Hilse) Cleve	DOVA	
				<i>Diploneis pseudovalis</i> Hustedt	DPSO	
Naviculaceae				<i>Adlafia bryophila</i> (Petersen) Moser Lange-Bertalot & Metzeltin	ABRY	
				<i>Adlafia minuscula</i> (Grunow) Lange-Bertalot	ADMS	
				<i>Chamaepinnularia evanida</i> (Hustedt) Lange-Bertalot	CHEV	
				<i>Chamaepinnularia mediocris</i> (Krasske) Lange-Bertalot	CHME	
				<i>Chamaepinnularia soehrensii</i> (Krasske) Lange-Bertalot & Kramme	CHSO	
				<i>Chamaepinnularia soehrensii</i> var. <i>hassiaci</i> (Krasske) Lange-Bertalot	CHSH	
				<i>Chamaepinnularia soehrensii</i> var. <i>musciicola</i> (J.B.Petersen) Lange-Bertalot	CHSM	
				<i>Chamaepinnularia</i> sp.1	CHSP1	
				<i>Kobayasiella subtilissima</i> (Cleve) Lange-Bertalot	KOSU	
				<i>Mayamaea atomus</i> (Kützing) Lange-Bertalot	MAAT	
				<i>Mayamaea fossalis</i> (Krasske) Lange-Bertalot	MAFO	
				<i>Mayamaea permitis</i> (Hustedt) Bruder & Medlin	MPMI	
				<i>Microcostatus krasskei</i> (Hustedt) Johansen & Sray	MKRA	
				<i>Navicula angusta</i> Grunow	NAAN	
				<i>Navicula</i> cf. <i>arvensis</i> Hustedt	NARV	
				<i>Navicula cryptocephala</i> Kützing	NCRY	
				<i>Navicula cryptotenella</i> Lange-Bertalot	NCTE	
				<i>Navicula difficillima</i> Hustedt	NDIF	
				<i>Navicula festiva</i> Krasske	NFES	
				<i>Navicula gregaria</i> Donkin	NGRE	
				<i>Navicula leptostriata</i> Jorgensen	NLST	
				<i>Navicula</i> cf. <i>longicephala</i> Hustedt	NLGC	
				<i>Navicula</i> cf. <i>menisculus</i> Schumann	NMEN	
				<i>Navicula notha</i> Wallace	NNOT	
				<i>Navicula obsoleta</i> Hustedt	NAOB	
				<i>Navicula radiosafallax</i> Lange-Bertalot	NRFA	
				<i>Navicula</i> cf. <i>recens</i> (Lange-Bertalot) Lange-Bertalot	NRCS	
				<i>Navicula reichardtiana</i> Lange-Bertalot	NRCH	
				<i>Navicula rhynchocephala</i> Kützing	NRHY	
				<i>Navicula rostellata</i> Kützing	NROS	
				<i>Navicula subrotundata</i> Hustedt	NSBR	
				<i>Navicula</i> cf. <i>subrynchocephala</i> Hustedt	NSRH	
				<i>Navicula tenelloides</i> Hustedt	NTEN	
				<i>Navicula vauchaeria</i> Petersen	NVAU	
				<i>Navicula veneta</i> Kützing	NVEN	
				<i>Navicula</i> sp.1	NAV1	
				<i>Navicula</i> sp.3	NAV3	
				<i>Navicula</i> sp.5	NAV5	
				<i>Navicula</i> sp.6	NAV6	
				<i>Navicula</i> sp.7	NAV7	
				<i>Navicula</i> sp.11	NAV11	
Stauroneidaceae				<i>Craticula submolesta</i> (Hustedt) Lange-Bertalot	CSBM	
				<i>Stauroneis anceps</i> Ehrenberg	STAN	
				<i>Stauroneis</i> cf. <i>kriegerii</i>	STKR	
				<i>Stauroneis thermicola</i> (Petersen) Lund	STHE	
Thalassiosiphales	Catenulaceae			<i>Amphora libyca</i> Ehrenberg	ALIB	
				<i>Amphora montana</i> Krasske	AMMO	
				<i>Amphora pediculus</i> (Kützing) Grunow	APED	
				<i>Amphora veneta</i> Kützing	AVEN	
Bacillariales	Bacillariaceae			<i>Hantzschia amphioxys</i> (Ehrenberg) Grunow	HAMP	
				<i>Nitzschia abbreviata</i> Hustedt	NZAB	
				<i>Nitzschia acidoclinata</i> Lange-Bertalot	NACD	
				<i>Nitzschia amphibia</i> Grunow	NAMP	
				<i>Nitzschia brevissima</i> Grunow	NBRE	
				<i>Nitzschia capitellata</i> Hustedt	NCPL	
				<i>Nitzschia</i> cf. <i>clausii</i> Hantzsch	NCLA	
				<i>Nitzschia fonticola</i> Grunow in Cleve & Möller	NFON	
				<i>Nitzschia gracilis</i> Hantzsch	NIGR	
				<i>Nitzschia</i> cf. <i>lacuum</i> Lange-Bertalot	NILA	
PHYLUM	CLASS	SUBCLASS	ORDER	FAMILY	SPECIES	TAXA CODE
					<i>Nitzschia linearis</i> (Agardh) W. Smith	NLIN
					<i>Nitzschia</i> cf. <i>microcephala</i> Grunow in Cleve & Moller	NMIC

		<i>Nitzschia nana</i> Grunow in Van Heurck	NNAN
		<i>Nitzschia palea</i> (Kützing) W. Smith	NPAL
		<i>Nitzschia paleacea</i> (Grunow) Grunow in Van Heurck	NPAE
		<i>Nitzschia paleaformis</i> Hustedt	NIPF
		<i>Nitzschia solgensis</i> Cleve-Euler	NSOL
		<i>Nitzschia terrestris</i> (Petersen) Hustedt	NTER
		<i>Nitzschia umbonata</i> (Ehrenberg) Lange-Bertalot	NUMB
		<i>Nitzschia valdestrata</i> Aleem & Hustedt	NIVA
Rhopalodiales	Rhopalodiaceae	<i>Epithemia adnata</i> (Kützing) Brebisson	EADN
		<i>Epithemia sorex</i> Kützing	ESOR
		<i>Epithemia turgida</i> (Ehrenberg) Kützing	ETUR
		<i>Rhopalodia gibba</i> (Ehrenberg) O. Muller	RGIB
		<i>Rhopalodia rupestris</i> (W.Smith) Krammer	RRUP
Surirellales	Surirellaceae	<i>Stenopterobia delicatissima</i> (F.W. Lewis) Brébisson ex van Heurck	STDE
		<i>Surirella biseriata</i> Brebisson in Brébisson & Godéy	SBIS
		<i>Surirella linearis</i> W.M. Smith	SLIN
		<i>Surirella roba</i> Leclercq	SRBA

Biogeography and lake morphometry drive diatom and chironomid assemblages' composition in lacustrine surface sediments of oceanic islands

Hydrobiologia

Cátia Lúcio Pereira^{1*}, Pedro Miguel Raposeiro¹, Ana Cristina Costa¹, Roberto Bao², Santiago Giralt³ and Vítor Gonçalves¹

¹CIBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, InBIO Laboratório Associado, Pólo dos Açores – Departamento de Biologia da Universidade dos Açores, 9501-801 Ponta Delgada, Portugal

²Faculty of Sciences, University of A Coruña, Campus da Zapateira s/n, 15071 A Coruña, Spain

³Institute of Earth Sciences Jaume Almera CSIC, Sedimentary Geology, Lluís Solé I Sabaris s/n, E-08028 Barcelona, Spain

*email: catiaalpereira@gmail.com

Online Resource 3 List of chironomid taxonomic type identified in surface sediment of 41 Azorean lakes and their respective codes.

TAXONOMIC TYPE	TAXA CODE
Camptocladius	Camp
Chaetocladius	Chae
Chironomus anthracinus type	Chi ant
Chironomus plumosus type	Chi plu
Cricotopus slyvestris type	Cri sly
Glyptotendipes pallens type	Gly pal
Glyptotendipes barbipes-type	Gly bar
Limnophyes	Limn
Macropelopia	Macr
Metriocnemus fuscipes type	Met fus
Micropsectra contracta type	Mic con
Micropsectra insignolobus type	Mic ins
Micropsectra type A	Mic A
Orthocladius type I	Ortho
Parachironomus varus type	Par var
Paramerina	Para
Paratanytarsus penicillatus type	Par pen
Polypedilum nubeculosum type	Poly nube
Polypedilum nubifer type	Poly nubi
Procladius	Proc
Psectrocladius barbimanus type	Pse bar
Psectrocladius sordidellus type	Pse sor
Pseudorthocladius	Porth
Pseudosmittia	Psmi
Rheocricotopus chalybeatus	Rhe cha
Thienemanniella clavicornis type	Thie cla
Zavrelimyia	Zavre

Biogeography and lake morphometry drive diatom and chironomid assemblages' composition in lacustrine surface sediments of oceanic islands

Hydrobiologia

Cátia Lúcio Pereira^{1*}, Pedro Miguel Raposeiro¹, Ana Cristina Costa¹, Roberto Bao², Santiago Giralt³ and Vítor Gonçalves¹

¹CIBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, InBIO Laboratório Associado, Pólo dos Açores – Departamento de Biologia da Universidade dos Açores, 9501-801 Ponta Delgada, Portugal

²Faculty of Sciences, University of A Coruña, Campus da Zapateira s/n, 15071 A Coruña, Spain

³Institute of Earth Sciences Jaume Almera CSIC, Sedimentary Geology, Lluís Solé I Sabaris s/n, E-08028 Barcelona, Spain

*email: catiaalpereira@gmail.com

Online Resource 4

Table 1 Percentages of dissimilarity between the five studied Azorean islands based on chironomids assemblages from surface sediments.

ISLAND	SÃO MIGUEL	TERCEIRA	PICO	FLORES	CORVO
SÃO MIGUEL	-	58.28	53.07	62.26	63.52
TERCEIRA	-	-	45.77	60.78	60.65
PICO	-	-	-	54.98	60.19
FLORES	-	-	-	-	53.73
CORVO	-	-	-	-	-

Table 2 Lineal distances in kilometers between the five studied Azorean islands.

ISLAND	SÃO MIGUEL	TERCEIRA	PICO	FLORES	CORVO
SÃO MIGUEL	-	170	246	511	519
TERCEIRA	-	-	96	352	364
PICO	-	-	-	265	274
FLORES	-	-	-	-	24
CORVO	-	-	-	-	-

Fig. 1 Relationship between the dissimilarity between the studied islands based on chironomid assemblages from surface sediments and the lineal distances between the studied Azorean islands.

