Impact of the historical introduction of exotic fishes on the chironomid community of Lake Azul (Azores Islands)

Pedro Miguel Raposeiro [a,*], Maria Jesus Rubio [b], Alba González [a], Armand Hernández [c], Guiomar Sánchez-López [b], David Vázquez-Loureiro [d], Valentí Rull [b], Roberto Bao [d], Ana Cristina Costa [a], Vítor Gonçalves [a], Alberto Sáez [e], Santiago Giralt [b]

[a] CIBIO, 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
[b] Institute of Earth Sciences Jaume Almera (ICTJA-CSIC), Lluís Solé i Sabarís s/n, E-08028 Barcelona, Spain
[c] Instituto Dom Luiz (IDL), Faculdade de Ciências, Universidade de Lisboa, 1749-016 Lisboa, Portugal
[d] Centro de Investigacións Científicas Avanzadas (CICA), Faculdade de Ciencias, Universidade da Coruña, 15701 A Coruña, Spain
[e] Department of Earth and Ocean Dynamics, Universitat de Barcelona, Martí i Franquès s/n, E-08028 Barcelona, Spain

ABSTRACT

Little is known about the effect of top predator introduction in historically fishless communities, especially on remote islands. This issue is important because it might strongly affect climate reconstructions derived from biota assemblages such as chironomids. Head capsule larval remains of chironomids have been studied in a 660 years lacustrine sedimentary sequence from Lake Azul (Sao Miguel Island, Azores archipelago) to assess the extent and timescale of the effect of the predator introduction occurring in this historically fishless lake. Analysis of similarity showed that the chironomid assemblage was statistically different before and after predator introduction (R = 0.78; p < 0.001). Abundance of chironomids was about 40% greater in the fishless lake period compared to the period in the presence of predator. Results show major change in chironomid assemblage coinciding with the first time of goldfish introduction (around 1790 CE), followed by carp (1890 CE) and pike (1979 CE) introductions. The composition of feeding group guilds changed following a pattern characterized by a decrease in abundance of detritivorous and predaceous taxa and an increase in abundance of grazing chironomid taxa. This study suggests that predator introduction was the most important factor affecting the chironomid assemblages in this natural, Azorean fishless lake, but predators did not affect all chironomid species. Other external forcings like major climate oscillations, anthropogenic activities in the catchment basin, and volcanic eruptions seem to play an additional role. The latest stage of the warm and arid Medieval Climate Anomaly (1000–1300 CE) favoured the occurrence of some warm-adapted chironomid taxa, which were absent through the Little Ice Age (ca. 1450–1850 CE) cool period.

© 2016 Published by Elsevier B.V.

1. Introduction

Today it is accepted that the introduction of non-native species is one of the main threats to autochthonous biodiversity globally and one of the major reasons for the worldwide biodiversity decline (e.g. Mooney and Cleland, 2001; Vitousek et al., 1996). Among these introductions, there is the particular case of freshwater fishes' introductions into highly restricted, susceptible and vulnerable environments, such as lakes (Fritts and Rodda, 1998; Gurevitch and Padilla, 2004; Sax et al., 2002). The disastrous ecological consequences of these introductions are direct and indirect impacts on food web structure and ecosystem function (Findlay et al., 2005). In lakes, a strong effect of top predators is common, with direct impacts on the diversity and abundance of prey populations (e.g., native fishes or invertebrates) and cascading effects down to lower trophic levels (Bystrom et al., 2007; Findlay et al., 2005). For example, introducing planktivore fishes in a fishless lake can decrease zooplankton densities, lowering grazing pressure on phytoplankton and resulting in increased chlorophyll *a* concentration and consequently reduced water clarity (Buchaca et al., 2011; Findlay et al., 2005; Skov et al., 2010). Also, increased nutrient availability through sediment disturbance and excretion by fish has direct effects on primary producers (quantity and diversity) and subsequent bottom-up consequences on food webs (Du et al., 2015). On the other hand, climate reconstructions developed from transfer functions that use biological assemblages, such as chironomids and diatoms (Fritz et al., 1991; Heiri et al., 2014), assume that the main driver that triggers the observed oscillations in their assemblages is climate fluctuations.

* Corresponding author.
  E-mail address: pedro.mv.raposeiro@uac.pt (P.M. Raposeiro).

Therefore, the introduction of top predators in lacustrine ecosystems might have significant effects on these climate reconstructions. To our best knowledge, these possible effects have not been properly assessed.

Oceanic islands are considered fragile ecosystems and highly vulnerable to biological invasion such as introduction of non-native species (Sax and Gaines, 2008). The Azores is a remote oceanic archipelago located in the middle of the Atlantic Ocean where fishless lakes were common landscape features before human settlement.

In the Azores archipelago, biodiversity impairment is a well-recognized consequence of biological invasions resulting from man-mediated introductions, especially of terrestrial flora (Silva et al., 2008). The impact of several fish introductions made between the late 19th and early 20th centuries (Flor de Lima, 1993; Vicente, 1956) in the naturally fishless Azorean lakes is poorly studied (Skov et al., 2010) although ecological problems in Azorean freshwater lakes are known to be a consequence of the recent introduction of exotic species such as the weed *Egeria densa*, crayfish *Procambarus clarkii* (Costa et al., 1996), and the freshwater limpet *Ferrissia fragilis* (Raposeiro et al., 2011a). Azorean lakes have simple food webs and low diversity typical of remote island systems (Matias et al., 2016; Raposeiro et al., 2012, 2016). Chironomids, one of the most abundant and diverse families of freshwater macroinvertebrates in the Azores archipelago (Raposeiro et al., 2011b; Raposeiro et al., 2009), are an important element in aquatic food webs, constituting approximately 50% of secondary production in lakes (Armitage et al., 1995). Consequently, chironomids play a crucial role in benthic food webs and in the trophic structure of ecosystems (Armitage et al., 1995). Chironomids are important prey for fish, but also play a key role as macroinvertebrate predators (Armitage et al., 1995). For example, the predaceous *Procladius culiciformis* (Linnaeus)

exhibited a positive feeding preference for ostracods, cladocerans and chironomids, and a negative choice for rotifers (Vodopich and Cowell, 1984). Chironomids are also sensitive to a variety of disturbances of anthropogenic and natural origin including changes in land use (Belle et al., 2016; Raposeiro et al., 2011b), climate (Heiri et al., 2011; Verbruggen et al., 2011), nutrient input (Brooks et al., 2001; Langdon et al., 2010), and predation pressure (Gilinsky, 1984; Goyke and Hershey, 1992; Skov et al., 2010).

The chitinised head capsules of chironomid larvae are well preserved in lake sediments (Skov et al., 2010), which make chironomids useful ad indicators of past environmental conditions (Walker et al., 1995; Cao et al., 2014) allowing us to uncover the main paleoecological and paleolimnological oscillations that have taken place in lake ecosystems. They can be useful proxies for past introductions and changes in fish population as the subfamily Tanypodinae includes both free-swimming and crawling predators (Vallenduuk and Moller Pillot, 2007) whose abundances are largely influenced by fish predation (Skov et al., 2010). Despite the potential of fossil chironomids as proxies for past fish introductions, there has been scarce information to reconstruct ecological conditions for this indicator group based on information from sedimentary archives (Skov et al., 2010).

In spite of morphological similarities of chironomid larvae, they display more differences in feeding strategies than any other aquatic insect group, and they can be grouped in several general feeding categories (Berg et al., 1995). Feeding groups (e.g. predators, grazers, detritivores) have been assigned for each taxon as in Wilson and Ruse (2005) and more recently in the work of Moller Pillot for the Netherlands and Adjacent Lowlands (Moller Pillot, 2009, 2014; Vallenduuk and Moller Pillot, 2007). The classification of chironomid larvae into functional
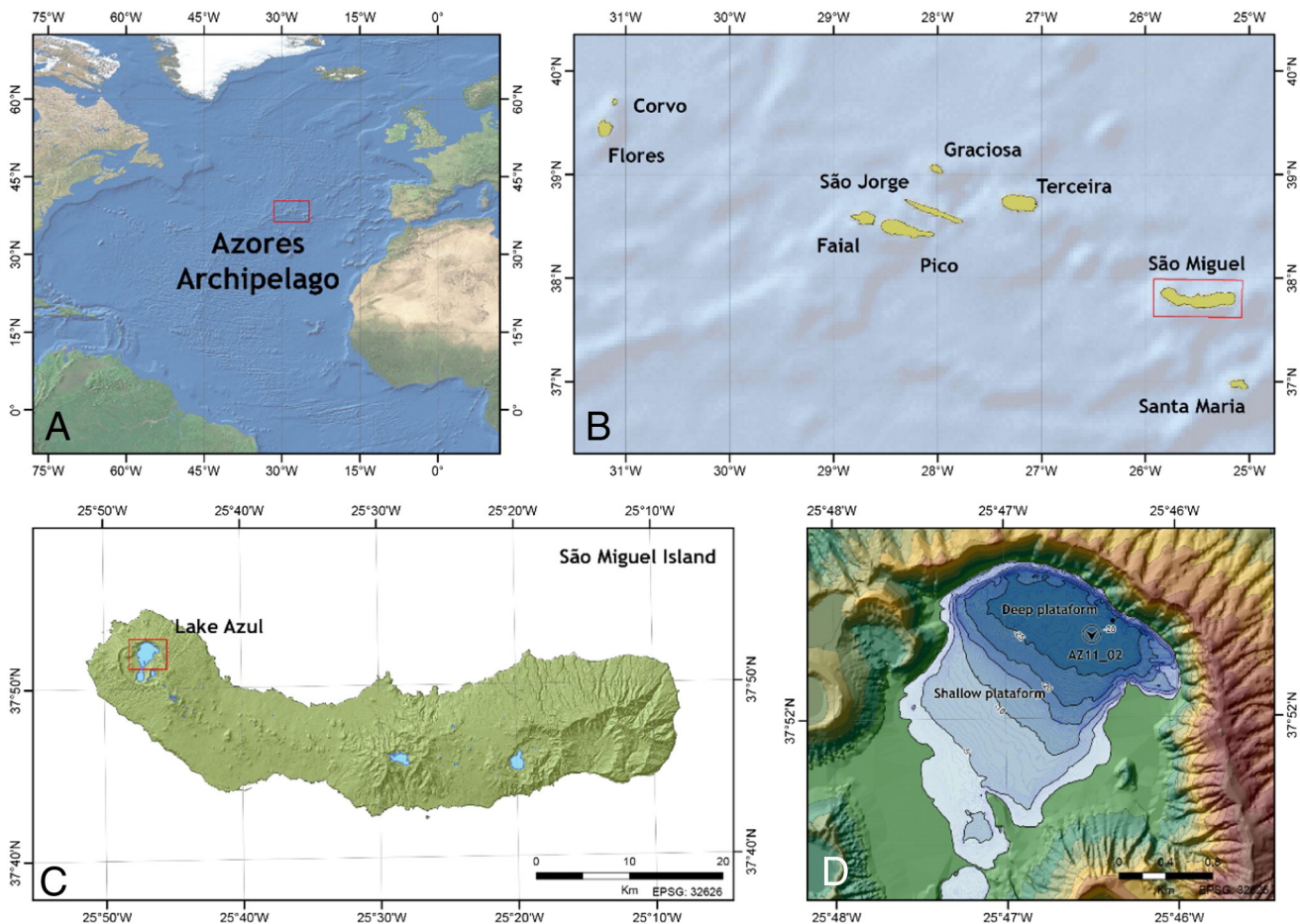

Fig. 1. Geographical location of the study lake, Lake Azul, São Miguel, Azores, Portugal. a) - Azores Archipelago in the Atlantic Ocean highlighted by a square; b) Location of São Miguel island; c) Location of Lake Azul; d) - Location of AZ11_02 in Azul lake.