Palaeogeography, Palaeoclimatology, Palaeoecology 479 (2017) 48–60

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Environmental history and vegetation dynamics in response to climate variations and human pressure during the Holocene in Bassa Nera, Central Pyrenees

Garcés-Pastor Sandra [a,*], Cañellas-Boltà Núria [b], Pèlachs Albert [c], Soriano Joan-Manuel [c], Pérez-Obiol Ramon [d], Pérez-Haase Aaron [a], Calero Miguel-Angel [e], Andreu Oriol [a], Escolà Nil [a], Vegas-Vilarrúbia Teresa [a,f]

[a] Department of Evolutionary Biology, Ecology and Environmental Sciences, Universitat de Barcelona, Barcelona, Spain
[b] Department of Prehistory, Ancient History and Archaeology, Universitat de Barcelona, Barcelona, Spain
[c] Department of Geography, Universitat Autònoma de Barcelona, Spain
[d] Botany Unit, Department of Animal Biology, Plant Biology and Ecology, Universitat Autònoma de Barcelona, Spain
[e] Institute of Earth Sciences Jaume Almera (ICTJA-CSIC), Barcelona, Spain
[f] Catalan Institute of Paleontology Miquel Crusafont, Spain

ARTICLE INFO

Article history:
Received 11 January 2017
Received in revised form 25 March 2017
Accepted 23 April 2017
Available online 25 April 2017

Keywords:
Montane–subalpine shifts
Pollen
Sphagnum peat
Charcoal
Pyrenees
Holocene

ABSTRACT

With the aims of investigating the causes of environmental changes in high mountain ecosystems during the Holocene in relation to climate forcings and identifying thresholds for vegetation community shifts, we performed a multi-proxy palaeoecological reconstruction based on two sediment cores from Bassa Nera, a lentic system located close to the montane–subalpine ecotone in the Central Pyrenees. Using pollen, plant macroremains, charcoal, chemical elements and loss-on-ignition at centennial to decadal resolution, we reconstructed the vegetation and lacustrine dynamics during the last 10,000 years. A montane pollen ratio was used as a palaeoecological indicator to track altitudinal shifts in high mountain vegetation, which was compared to the ice-rafted debris index (IRD) as a proxy for summarizing the climatic influence of the North Atlantic Circulation. Our results show upward shifts of deciduous forest and its presence in Bassa Nera from the onset of the Holocene until 4200 cal yr BP, when it was replaced by coniferous taxa. The montane ratio showed a link between vegetation and North Atlantic influence, while changes in *Sphagnum* macroremains and aquatic taxa allowed description of local ontogenic changes from the initial pond to the present peatland. The loss-on-ignition record showed some flood events at Bassa Nera between 4500 and 3900 cal yr BP. The studied proxies allowed inferences concerning anthropic pressure in the catchment through grazing activities by 7300 cal yr BP and the appearance of cereal agriculture around 5190 cal yr BP. The highest human pressure occurred in the late Bronze Age, Roman Period and Middle Ages.

1. Introduction

The development of environmental assessment tools to predict how current climate change will affect natural ecosystems is essential to apply proper management measures. Palaeoenvironmental reconstructions are crucial to understand ecosystem sensitivity and past environmental shifts, as they help to distinguish between the effects of climatic and anthropogenic forcings (Last and Smol, 2001; Willis and Birks, 2006; Catalan et al., 2013). Mountain ecosystems are well-suited to study such changes, since their hard environmental conditions make them less prone to intensive human influence.

The onset of the Holocene, characterised by relatively warmer temperatures and an increase in humidity in Europe (Walker, 1995), prompted a rapid expansion of deciduous forests in southwest European mountains (Jalut et al., 2009; Pérez-Obiol et al., 2011), including the Pyrenees (Benito et al., 2008; Montserrat-Martí, 1992). By the Middle-Holocene, a southward shift of the North Atlantic westerly jet (Bond et al., 2001) led to a change in precipitation seasonality (Pla and Catalan, 2005), a drastic decline in deciduous taxa and a progressive consolidation of conifers in the Pyrenees (González-Sampériz et al., 2006; Pèlachs et al., 2011). Such changes in plant community composition suggest that the North Atlantic climatic variability had sufficient magnitude and duration to affect the Pyrenean ecosystems and force them to cross a threshold into a different state. However, the precise

* Corresponding author.
E-mail addresses: sgarcepa7@alumnes.ub.edu (S. Garcés-Pastor), albert.pelachs@uab.cat (A. Pèlachs), joanmanuel.soriano@uab.cat (J.-M. Soriano), ramon.perez@uab.cat (R. Pérez-Obiol), aaronperez@ub.edu (A. Pérez-Haase), tvegas@ub.edu (T. Vegas-Vilarrúbia).

http://dx.doi.org/10.1016/j.palaeo.2017.04.016
0031-0182/

features in the response of deciduous and conifer species to climatic shift are not yet fully understood, and their study becomes even more complicated when anthropogenic influence is taken into account.

With the aim of investigating how the high mountain ecosystems of the Central Pyrenees responded to the Holocene climate and anthropogenic forcings, we performed a multi-proxy palaeoecological reconstruction of Bassa Nera (BSN), a pond with a ring of *Sphagnum* moss close to the montane-subalpine boundary of the Aiguamòg valley (Aran valley). There are several palaeoecological studies in the Central Pyrenees covering the Holocene that record a marked climate variability with well-defined arid and cold events (Pla and Catalan, 2005; González-Sampériz et al., 2006; Pérez-Sanz et al., 2013), vegetation responses through treeline shifts and biomass-fire interactions (Cunill et al., 2013; Gil-Romera et al., 2014).

Regarding human influence, the Central Pyrenees have been occupied and exploited by prehistoric societies since at least the Neolithic (Ejarque et al., 2010; Gassiot et al., 2014) through fire and complex land use management (Bal et al., 2010; Pérez-Obiol et al., 2012). Phases of higher anthropogenic pressure in high mountain areas are known since the Early and Middle Neolithic, with an important threshold in the Early Bronze Age (Gassiot and Jiménez, 2006; Miras et al., 2007). Since then, it has been widely assumed that the configuration of high mountain landscapes has been influenced by humans (Ejarque et al., 2010; Bal et al., 2011; Cunill et al., 2013), or at least that humans have accentuated the effects of climatic constraints on vegetation during the late Holocene (Jalut et al., 2009) through mining activities, farming or cattle raising (Pèlachs et al., 2009a; Cunill et al., 2013; Garcés-Pastor et al., 2016). In this study, we perform a high-resolution reconstruction of vegetation in order to detect the onset of the anthropic pressure in Bassa Nera caused by grazing and agriculture farming.

Pèlachs et al. (2011) found a close coupling between regional climatic patterns using the ice-rafted debris index (IRD; Bond et al., 2001) from the North Atlantic and the accumulation of organic matter in a mountain wetland system in the Central Pyrenees (Pèlachs et al., 2011). However, it is advisable to check whether this coupling between climatic influence and organic matter deposition may be generalized to other lentic systems in order to test the applicability of the IRD to palaeoecological reconstructions. Hence, this paper studies the response of organic matter accumulation in Bassa Nera to North Atlantic regional climatic patterns and compares it with similar regional essays. In a previous study, Garcés-Pastor et al. (2016) introduced a montane pollen ratio that was useful for monitoring local upward migrations of the montane-subalpine boundary. The present work uses this montane ratio to track the response of high mountain vegetation to the Holocene climate variability and North Atlantic influence (IRD) and, if possible, to identify possible thresholds in vegetation communities. In this paper, we combine diverse proxies (pollen, charcoal, macroremains, organic matter, chemical elements and sedimentology) from two independent records of Bassa Nera spanning the Holocene with the following objectives: (1) To reconstruct the local vegetation dynamics of BSN; (2) to evaluate the ecosystem response of the area to climate forcings and North Atlantic influence, describing the main arboreal dynamics at the local level as well as identifying thresholds in vegetation communities and their possible causes; (3) to test the response of organic matter indicators such as LOI in front of North-Atlantic regional climatic patterns (IRD), comparing the results from BSN to those obtained from other Pyrenean systems; and (4) to assess the human influence on the BSN region, determining the point at which this influence became strong enough to be detectable and how it was affected by the climatic patterns.

2. Study area

2.1. Environmental and geographical settings

The Bassa Nera (42° 38′ 18.5″ N, 0° 55′ 27.6″ E, 1891 m a.s.l.) is a small lentic system from glacial origin located in the peripheral zone of "Aigüestortes i Estany de Sant Maurici" National Park (PNAESM) (Fig. 1). Its surface area is 2.01 ha, with a maximum depth of 5 m, and it drains by a small outlet into the Aiguamòg River. This pond is surrounded by mixed peat bogs and it is currently in the final stages of infilling (Pérez-Haase and Ninot Sugrañes, 2006, 2017). The climate is subalpine with Atlantic influence and precipitation is well distributed along the seasons (annual average = 1152 mm) (Ninyerola et al., 2003). Mean annual temperature is 4.25 °C, being January the coldest month (−3 °C in average) and July the warmest (14 °C in average). The BSN basin lies on a granodiorite bedrock from the Maladeta batholith, which dates from the Carboniferous-Permic age (Roca i Adrover et al., 2010). The main peat communities are geogenous fens (*Scheuchzerio-Caricetea fuscae*) and ombrogenous bogs (*Oxycocco-Sphagnetea*) (Pérez-Haase et al., 2012). The BSN is surrounded by a mixed conifer forest of *Pinus mugo* subsp. *uncinata* (Ramond) Domin. and *Abies alba* Mill., with *Rhododendron ferrugineum* L. in the understory and Poaceae meadows. Cañellas-Boltà et al. (2009) described the montane and subalpine vegetation altitudinal belts where the catchment area lies. The montane belt (<1600 m) is composed by deciduous oak forests of *Quercus petraea* (Mattuschka) Liebl. with *Betula pendula* Roth.; riverine forests (dominated by *Alnus glutinosa* L., *Fraxinus excelsior* L., and *Salix* spp.); forests with *Tilia platyphyllos* Scop., *Prunus avium* L., and *Corylus avellana* L.; and mixed forests of *Betula pendula* Roth. and *Pinus sylvestris* L. The subalpine belt (1600–2250 m) is dominated by coniferous forests of *Abies alba* and *Rhododendron ferrugineum* at the lowest parts and *Pinus mugo* subsp. *uncinata* with *R. ferrugineum* at the upper stages. Wetlands are mainly occupied by *Trichophorum cespitosum* subsp. *cespitosum* (L.) Hartm. communities, assemblages of *Juncus balticus* Willd, subsp. *pyrenaeus*, *Carex rostrata* Stokes beds., *Caltha palustris* L. flushes and *Sphagnum* peat bogs (carpets and hummocks) (Pérez-Haase and Ninot Sugrañes, 2006). This part of the valley has experienced low human pressure through pasturing and farming during the last millennium (Garcés-Pastor et al., 2016). Since the rural exodus of mid-20th century to the creation of the PNAESM in 1955, grazing, forest exploitation and hydroelectric electricity generation were the only activities. Afterwards, tourism has become an important activity in the national park.

3. Material and methods

3.1. Coring, sampling, dating and sedimentology

Two cores (PATAM-12 and BSN-6), separated by 47 m, were retrieved from the *Sphagnum* mire surrounding Bassa Nera (Fig. 1). Core PATAM-12 provides a detailed record of the last seven millennia, but lacks the beginning of the Holocene. For this reason, we also studied core BSN-6, which covers the last ten thousand years and provides a wider environmental framework. The core BSN-6 (core A, 270 cm long) was collected in 2011 through the percussion and recover in one step of a 3 m PVC tube on a hummock composed by *Sphagnum magellanicum* and *S. capillifolium* (Fig. 1). The core PATAM-12 (core B, 706 cm long) was obtained in 2007 with a "Russian" corer (Jowsey, 1966) on the *Sphagnum* quaking carpets (*Caricion lasiocarpae*) that surround the pond. Core A was sliced every 1 cm and core B every 3 to 5 cm. The chronological framework was based on AMS radiocarbon dates from peat and macroremains obtained at Beta Analytic Radiocarbon Dating laboratory (Miami, USA) and Keck Carbon Cycle (Irvine, USA), published in Pèlachs et al. (2016) and Garcés-Pastor et al. (2016). The radionuclide analysis (^{210}Pb) for dating purposes of the uppermost 40 cm of core A was carried out at the Laboratory of Environmental Radioactivity of the Universitat Autònoma de Barcelona (UAB, Spain). The supported ^{210}Pb was found at 30 cm depth and ^{210}Pb activities were determined by α-spectrometry through ^{210}Po in equilibrium (Sanchez-Cabeza et al., 1998). Ages were calibrated with IntCal13.14C curve (Reimer et al., 2013) and the age–depth models (Fig. 2) were performed with Clam 2.2. software using *Smooth*