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Land use development and environmental responses since the Neolithic around Lake Paladru in the French Pre-alps

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ABSTRACT

The Lake Paladru sedimentary archive documents the past 10,000 years of the environmental history of the French Pre-alps. The archive's information on vegetation dynamics, fire activity and soil erosion serves to reconstruct a continuous dynamic record of land use over the last 6000 years. This multi-proxy approach serves to document the effects of successive human settlements on the environment at the watershed scale. First, discrete human impacts were identified during the Middle Neolithic that have not yet been confirmed by archaeological discoveries in the watershed. Developments of agropastoral activity have been recorded during the Late Neolithic (the period of the pile-dwelling archaeological site "Les Baigneurs") and the Bronze Age, and the practice of slash-and-burn is documented by the records of fires. During the Iron Age and the Roman period, agropastoral activities (livestock farming and cereal cultivation) became continuous. They involved an intensification of human effects with a rapid and high-amplitude increase in soil erosion and a shift in the use of fire from an instrument for clearing land to an agropastoral landscape management tool. The Medieval period was characterized by the spatial expansion and diversification of crops. Results of this study have located the "thousand-year" pile dwelling sites such as "Colletière" in a longer phase of human occupation that deeply and sustainably modified the surrounding landscape of the lake. Beginning in the Modern period, the proxies used in this study served to record a new shift in land use marked by extensive clearing and the abandonment of most crop areas. This shift was linked to the expansion of industrial activities and subsequently to their abandonment during the 20th century.

1. Introduction

Human effects on ecosystems have increased exponentially over the past few centuries, and the development of an overview of this increase in anthropogenic forcing from a long-term perspective is now a major challenge for palaeoenvironmental studies (Dearing and Jones, 2003; Dearing, 2006; Seddon et al., 2014). Since the beginning of agricultural development in the Neolithic until the present, humans have never stopped shaping their environment to obtain required resources. Over millennia, they were able to change their environmental modes of operation and to adapt their technology and techniques to changing socio-economic and political contexts but also to variable climate and local environmental conditions (Doyen et al., 2013a,b; Enters et al., 2008; Ledger et al., 2015). Thus, it appears necessary to retrace the history of land use to determine the amplitude and variability of anthropogenic impacts on ecosystems by means of comparative studies that confront past ecological and climate dynamics with archaeological evidence associated with human settlements.

Lake systems are suitable for this type of enquiry due to the favourable conditions that they provide for the preservation of both palaeoenvironmental markers and archaeological remains. Pile-dwelling sites discovered on the borders of alpine, subalpine and Jurassian lakes represent privileged archives for studying human/environment relationships (Brochier et al., 2007; Gauthier et al., 2008; Jacomet, 2009; Magny, 1993; Pétrequin and Pétrequin, 1988; Richard, 1997; Rösch, 1992). The palaeoenvironmental study of a sediment core collected in the central portion of a lake, beyond a strict archaeological context, appears to complement other data well in approaching these relationships, not only focused on one site and over a limited period but at the scale of an entire catchment and over long periods of time. Sediment records serve to integrate the effect on the ecosystem of all archaeological sites that are dispersed within a watershed.

Lake Paladru (Isère, France) offers a privileged framework for addressing these human-environment interaction issues as they emerge and persist throughout the Holocene (Bocquet, 2012; Brochier et al., 2007; Simonneau et al., 2013). The local archaeological context is particularly rich and well documented by numerous archaeological studies conducted at pile-dwelling sites (Bocquet, 1987, 2012; Colardelle and Verdel, 1993), field explorations, and research in historical archives within the catchment area. The main objectives of the present paper

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are (i) to identify the different phases of human influence in the watershed of Lake Paladru; (ii) to characterize their successive effects on the ecosystem over the past 10,000 years, comparing plant, fire and soil erosion dynamics with available archaeological data; (iii) to determine how fire activity have been influenced by land use changes over time.

2. Settings

2.1. Environmental settings

Lake Paladru (5°32′06″E, 45°27′18″N) is located at 492 m a.s.l in the French Alpine foreland (Fig. 1a). This moraine-dammed lake (3.92 km^2, 5 km long and 0.7 km wide) was formed during the Last Glacial Maximum (Fig. 1b). The lake is fed by 2 streams to the west and to the north (the Surand and the Courbon Rivers), and the lake waters drain into one stream (the Fure River) on its southern edge. Currently, the water depth is artificially maintained by a valve system (introduced in AD 1868) at a depth of approximately 36 m.

The watershed has an area of 55 km^2 and is bordered by hills reaching 660 to 780 m a.s.l. The bedrock is formed primarily by Miocene molasses of the alpine belt, covered in several places by Pleistocene moraines and modern alluvial deposits. The vegetation cover consists of grasslands, fields and deciduous forests (*Alnus glutinosa*, *Carpinus betulus*, *Castanea sativa*, *Fagus sylvatica*, *Fraxinus excelsior*, *Quercus petraea*, *Quercus pubescens* and *Quercus robur*). The area has a sub-continental climate: the mean annual precipitation rate is 1160 mm per year, while the mean July and January temperatures are 19 °C and 2 °C, respectively.

2.2. Archaeological and historical settings

The oldest lakeshore settlement dates from the Late Neolithic and is located on a site named "Les Baigneurs" (Fig. 1c). This site was occupied twice between 2750 and 2650 BC (Bocquet, 1974; Bocquet et al., 1987). Two artefacts, a hook and a wooden pile, dated ca. 1100–900 BC, suggested a human presence around Lake Paladru during the Bronze Age (Bocquet, 2012). No settlement is locally documented for the Iron Age period, but artefacts dated from the 1st century BC to the 4–5th centuries AD and occurring at 12 sites located primarily in the littoral zone of the lake attested to new settlements during the Roman period (Dècle and Verdel, 2012) (Fig. 1c). The first lakeshore Medieval remains corresponding to 3 contemporary villages (fortified and aristocratic settlements with agricultural and handicraft activities) were occupied from AD to AD (Colardelle and Verdel, 1993; Fig. 1c). After AD , the high density of sites identified within the watershed (5 castle mounds and 4 sites with earthen fortifications) reflected the construction of many small centres of power. At the end of the 11th century AD and at the beginning of the 12th century AD, power was centralized by more powerful lords. The fortified sites were abandoned or reused and replaced by powerful castles (Clermont, Paladru and Virieu). Habitats and rural activities were then grouped permanently in the vicinity of these main castles (Colardelle and Verdel, 2002). During the 12th century AD, the establishment of the monastery Silve Bénite (northwest of the lake) markedly influenced the geography of the human population. An additional influence on the areas human geography was the installation of handcraft sites beginning in the 14th century AD (ironworks, water-powered sawmill, textile crafts, fulling mill) in valley bottoms to take advantage of hydraulic power (Colardelle and Verdel, 2002). During the 19th century AD, the Industrial Revolution accelerated the development of the valleys (paper mills, weaving, sawmill and metalworking industry). Such activities continued to contribute to the economic and social life of the area until the 20th century AD.

3. Materials and methods

3.1. Coring and geophysical logging

The sedimentary infill of the lake was imaged by high-resolution seismic profiling with a sub-bottom profiler operating at 12 kHz deployed on an inflatable boat and coupled with GPS navigation. Several profiles were made and used to select the location for the coring site PAL 09 (5°32′348″E-45°27′478″N) characterized by continuous sedimentation and devoid of major landslides (Chapron et al., 2015; Simonneau et al., 2013). Five overlapping cores were taken at the deepest part of the basin (30 m deep) (Fig. 1b) using a stationary piston corer (UWITEC system) operated from a surface platform.

Along the 12 m length of the cores, magnetic susceptibility and gamma density were measured every 5 mm with a Multi Sensor Core Logger (Geotek). Sediment colour variations were checked using high-resolution pictures. These 3 parametres were used to correlate the sedimentary units of core sections to create a master core without gaps (PAL09-MC). All further analyses were performed on the first 4 m of the PAL09-MC sequence which correspond to the Holocene period.

Geochemical core logging was performed by X-ray fluorescence using an ITRAX core scanner (CEREGE laboratory, Aix-en-Provence, France) to track the occurrences of allochtonous mineral inputs. The relative abundances of Ca, Si, Ti, K, Fe and Al were measured all along the sequence PAL09-MC using a chromium tube with the same setting (30 kV, 12 mA), a count-time of 15 s and a sampling step of 5 mm.

3.2. Chronology

The chronological control was based on a combination of (i) 14 radiocarbon dates obtained at the Poznan Radiocarbon Laboratory and at the Laboratory LMC14 in Gif-sur-Yvette on diverse macro-remains of terrestrial origin (leaf, seed and wood), (ii) 3 ages estimated for the main late-glacial/early-Holocene transitions indicated by the pollen stratigraphy and the geochemistry data and (iii) radiometric markers (210Pb, 137Cs) measured every 5 mm for the topmost 16 cm (Doyen et al., 2015; Simonneau et al., 2013). An age-depth model within a 95% confidence envelope was constructed using the R script Clam (loess model; Blaauw, 2010; Fig. 2). The description of the age-depth model and the explanations about the two rejected radiocarbon date are available in Doyen et al. (2015).

3.3. Pollen analyses

A total of 48 sediment subsamples, each 2 cm thick with a volume of 1.8 cm^3 were taken at 8 cm intervals along core PAL09-MC. They were prepared for pollen analysis using the standard procedure described by Faegri and Iversen (1989). Pollen grains were identified and counted under 500× microscopy. Between 300 and 600 pollen grains of terrestrial plants (TLP, Total Land Pollen) were counted in each subsample excluding the dominant taxon. Pollen identification was performed using determination keys (Beug, 2004), books of photographs (Reille, 1992) and a reference collection of modern pollen types. Pollen counts were expressed as percentages of TLP excluding pteridophytes, aquatics and *Cannabis*/*Humulus* pollen types from the total pollen sum. Pollen data were divided in Local Pollen Assemblage Zones (LPAZ) via constrained incremental sums of squares cluster analysis (CONISS) performed from the relative abundance of pollen taxa. The broken stick criterion was used to select significant LPAZ.

3.4. Charcoal analyses

For microscopic charcoal analysis, 200 contiguous sediment subsamples, each 2 cm thick and with a volume of 2 cm^3 were taken along core PAL09-MC. Micro-charcoal particles were extracted using the procedure