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Human settlement and landscape dynamics on the coastline south of the Gironde estuary (SW France): a multi-proxy approach

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The Gironde estuary in SW France is the largest in Western Europe and has attracted human populations since prehistoric times. From the 1970s to the 1990s, intense archaeological research was undertaken on the long and highly dynamic coastline just south of the estuary mouth. In recent years, the combined action of increased coastal erosion and human pressure has proved a serious threat to the integrity of archaeological sites in the area. As a consequence, a whole array of previously unrecorded archaeological remains across the intertidal zone and coastal strip is being exposed. In this context, innovative interdisciplinary research since 2014 is yielding new information about the settlement and landscape dynamics and about the long-term interaction between human societies and the environment. The sedimentary context and the exceptional preservation conditions of organic remains have made possible a multi-proxy approach combining archaeological, geomorphological, palaeobiological and archaeoentomological methods. In this paper we discuss the different approaches and the way they jointly contribute to the project. The results obtained so far from this multi-proxy approach challenge the traditional view of the historic occupation and the landscape dynamics around the Gironde estuary from prehistoric times to antiquity. They show that the intense occupation of this area during certain periods of human history is related to the development of marshy environments, which can now be analyzed at higher temporal resolution owing to this approach.

Keywords: settlement dynamics, coastal landscape evolution, multi-proxy approach, prehistory, antiquity, SW France

Introduction

Coastal and wetland environments are increasingly becoming a focus for archaeological and palaeoenvironmental research. They yield answers to a whole string of questions

about past human settlement, exchange, mobility or resource exploitation on marine boundaries, to cite but a few (Fitzpatrick et al. 2015). In addition they provide access to a series of palaeoenvironmental and sedimentological records that can help unfold the history of past climates from tens to thousands of years ago. Paradoxically the integrity of such progressively formed archaeological and palaeoenvironmental records is seriously threatened today in coastal areas around the globe by the combined action of the effects of current climate change (e.g. sea-level rise, coastal erosion and more frequent extreme weather events) and human pressure that can destroy them in a matter of days or even hours (e.g. Ashmore 1994; Erlandson 2008). While awareness and mitigation strategies at different levels have been multiplied in the last few years (see e.g. Dawson et al. 2017), the loss of scientific information on past societies, climates and landscapes continues. This problem is often exacerbated by the exceptional nature and preservation conditions of the sediments, biofacts and artifacts found in some coastal and wetland environments (e.g. owing to the presence of waterlogged soils). The erosion and eventual destruction of these proxies will prevent us in the short to medium term from accessing irreplaceable information about human history and the history of human–environment interactions.

The Médoc area in South-West France is a paradigmatic example of this overall situation. Located on the southern margin of the Gironde estuary (Figure 1), the area is currently dominated by sand dunes that overlie a series of waterlogged clay and peaty levels that are especially abundant in the north of the Médoc between the Pointe de Grave and Montalivet (Durrieu de Madron et al. 1999; Herbert et al. 2011; Charria et al. 2013; Ba and Senechal 2013; Castelle et al. 2015). The existence of this particular sedimentary context has allowed the preservation of a whole array of archaeological and

palaeobiological remains that now lie in the intertidal area; these remains are progressively being exposed and washed out as the dune horizon retreats as a result of storm surges, wave impact and sea level rise. The rate of coastline retreat in the area is extremely alarming, ranging from c. 5 to c. 40 m/yr (Aubié and Tastet 2000; Bulteau et al. 2014; Castelle et al. 2018).

Early research in this region included the excavation and first palynological analyses of the sites of La Négade (Soulac-sur-Mer, 1966–1985, directed by J. Moreau; Moreau 1971) and La Lède du Gulp (Grayan-et-L'Hôpital, 1972–1993, directed first by G. Frugier and then by J. Roussot-Larroque; Frugier 1982; Roussot-Larroque and Marambat 1989). Sparse information about other archaeological finds was also published during this period by members of the Association Méduillienne d'Archéologie et d'Histoire du Médoc (chaired by J. Moreau) but the integration of archaeological studies in some of the interdisciplinary programs that were developed in the region during the 1990s was marginal (e.g. Tastet et al. 1996). During the 2000s most archaeological activity along the coastline south of the Gironde estuary mouth came to a halt.

Following the effects of the severe winters of 2013 and 2014, and owing to the extremely rich archaeological and palaeoenvironmental repositories identified, a new research program was launched to analyze the nature and chronology of the human occupation of the region, the long-term environmental dynamics, the landscape changes and, resulting from the combination of these, to investigate the human–environmental interactions in the area¹. This race against coastal erosion prompted the implementation

1 This programme has benefited from the LitAq and Fast-LitAq projects (funded by the LabEx LaScArBx and LabEx COTE, coord. F. Verdin, and F. Eynaud supported by the French National

of a dedicated inter-disciplinary multi-proxy approach and the setting up of original lines of research.

Contexts, materials and methods

The geomorphological and sedimentary contexts

The research focused on two different sectors of the coastal strip: the northern beach of L'Amélie (Souillac-sur-Mer) and the sedimentary depression of La Lède du Gurg (Grayan-et-L'Hôpital). Landscapes from those neighboring areas are shaped by poorly expressed geological structures with low reliefs related to Quaternary alluvial, estuarine and wind-blown cover (i.e. mainly coastal dunes in the sites studied) which mask the Tertiary substratum and its tectonic heritage (e.g. Fabre 1939; Dubreuilh and Marionnaud 1972). The northern part of the Médoc peninsula is characterized by late Quaternary deposits, occupying nine-tenths of the total area. The ante-Holocene substrate comprises Eocene and Oligocene limestone formations generally capped by Pleistocene gravel fluvial terraces (e.g. Fabre 1939; Daguin 1948; Dubreuilh 1971). These old limestones are marked by soft deformation and by karstic depressions (Dubreuilh and Marionnaud 1972; Courrèges 1997). Holocene formations consist mostly of sedimentary units extending laterally to the Gironde estuary or to the Atlantic coast, with a clear west–east zonal gradient ranging from massive sand dunes to muddy

Research Agency/ANR in the framework of the Investments for the Future Program, within the Cluster of Excellence COTE – ANR-10-LABX-45 and within the Cluster of Excellence LaScArBx – ANR-10-LABX-52, and the EC2CO DRIL action for the latter, coord. F. Eynaud, 2016-2018) and, more recently, from the ECOREST project (funded by the LabEx LaScArBx, coord. F. Verdin, 2018-2021).

estuarine marsh (including peat) deposits (e.g. Dubreuilh and Marionnaud 1972; Coquillas et al. 2004; Bosq et al. 2019; Stephan et al. 2019; Faye et al. 2019). Previous studies carried out in the southern coastal marshes of the Gironde estuary suggest that, as relative sea-level rose to the elevation of the relatively flat fluvial terraces, these areas were flooded rapidly, resulting in rapid expansions of swamps and salt-marshes in lateral bay areas (Diot and Tastet, 1995; Pontee et al. 1998; Diot et al. 2002). The development of these coastal marshes was favored by the presence of a large dune barrier stretching northwards, forming the north-Médoc Peninsula. Although the Holocene evolution of Aquitaine dune complexes has been studied in detail by many authors (Dubreuilh and Marionnaud 1972; Tastet, 1998; Clavé, 2001; Clarke et al. 2002), few analyses have been made of the construction phases of the north-Médoc deposits since the last deglaciation.

Throughout this research program, the interdisciplinary approach has generated an integrated methodology. Systematic geomorphological surveys of vestigial sedimentary deposits unearthed by the current erosion situation were conducted simultaneously with archaeological campaigns. In addition, mechanical excavations and coring were carried out within archaeological sites or in their close vicinity. Combining topographic monitoring using differential GPS (DGPS) and drone surveys, terrestrial laser scanning (TLS) acquisition, sediment sampling and analysis (radiocarbon dating, micromorphology, grain-size analysis, etc.) and micropalaeontology of fossil content, geomorphological and sedimentological analyses were jointly used to better constrain the palaeoenvironmental evolution of L'Amélie beach and La Lède du Gurd. All stratigraphic and palaeoenvironmental data recovered were recorded in three

dimensions (x, y, z coordinates) and integrated into a GIS platform and database in order to obtain a complete sedimentary sequence. The resulting chronostratigraphic framework for the North-Médoc coast has allowed palaeogeographic and coastal dynamic reconstructions for the past 10,000 years.

At L'Amélie beach the significant Holocene sedimentary sequence highlighted the presence of a large Gironde palaeochannel infilled by two generations of intertidal marsh protected by a coastal dune barrier. An episode of marine erosion interrupted the marsh sequence leading to a dune barrier retreat and transport of previous deposits inside the marsh. Finally the area was buried by eolian sand; inside this coastal barrier two main periods of dune stability were recognized (Stéphan et al. 2019).

The site of La Lède du Gurp some 2 km south of L'Amélie contains an accumulation of sandy clays and peats covered by modern aeolian sands (e.g. Roussot-Larroque and Villes, 1988; Tastet, 1999) in a depression formed by karstification processes. This site corresponds to one of the frequent wet depressions locally called 'lette' or 'lède' located along the foot of the landward slope of modern dunes (Figure 2).

The archaeological context: nature and constraints

The high density of archaeological finds recorded in the area since the nineteenth century (e.g. Dulignon-Desgranges 1880) bears witness to occupation of these coastal and marshy landscapes throughout the Holocene. With the exception of the aforementioned sites of La Négade and La Lède du Gurp, archaeological finds appear mostly as isolated structures and artifacts. Sometimes the finds are embedded in palaeosols, but mostly they appear as individual excavated circular basins or pits –

usually wood-lined –, salt production debris, wattle structures and animal and vehicle tracks (Figure 3). The exceptional preservation of remains because of the waterlogged clay sediments provides us with some unusual archaeological and palaeobiological information: ancient wood, leaves, nuts and bones are frequent discoveries. From the Mesolithic levels of La Lède du Gurg to the antique remains of L'Amélie beach, these organic finds are present throughout the human occupation sequence of the area, making it possible to analyse long-term changes in the uses and exploitation of the area (see below, Results and Discussion). In spite of these overall conditions, bone collagen is poorly preserved as a result of lixiviation, meaning absolute dating of organic materials is often dependent on dating of wood samples alone.

As is the case nationally in France (Billard et al. 2019) and internationally (e.g. Menotti and O'Sullivan, 2012), fieldwork and the handling of organic remains in such intertidal spaces are subject to extremely tight constraints requiring specific working protocols. Intervention times limited by the effects of the tides, draining of waterlogged ground from the excavated areas or the changing visibility conditions of archaeological structures – as a result of re-deposition of sediments as the tide changes – are just a few such constraints. In addition to this, the extreme coastal erosion conditions mean that archaeological and palaeobiological remains are exposed, eroded and destroyed in a matter of weeks, days or even hours. To address this situation, it was decided from the beginning of the program to systematically survey and monitor each archaeological entity identified by us or by our network of collaborators. Spot surveys are made at any time of year whenever a new structure or set of remains are discovered while scheduled surveys are carried out, mainly in winter, when the offshore sand is stripped from the

beach. It is thus possible to program throughout the seasons the archaeological interventions on the most directly threatened remains. This twofold survey strategy has made it possible to precisely locate – spatially and chronologically – the whole record of archaeological remains that speaks of the long history of human occupation of the area.

Excavations take place during spring tides to take advantage of the longest possible interval. All the structures identified as a result of survey or excavation are also recorded by means of structure-from-motion digital photogrammetry and/or 3D scanning. The organic materials recovered are cleaned the same day in the field laboratory and then transported either to the Conservation and Study Center of the Certes-Graveyron area (especially wood) or to the Université de Bordeaux-Montaigne facilities in Pessac (wood and smaller organic materials) to be stored under suitable vacuum, humidity and temperature conditions. Structural elements and other significant finds are subsequently individually digitized by means of photogrammetry or laser-scanning. Exceptional finds like wattle structure ST7 (see below) are subject to further analytical and conservation treatment.²

A multi-proxy approach to the settlement and landscape dynamics

Owing to these characteristics and constraints, the combination of archaeological, palaeoenvironmental, palaeogeographic, palaeobiological and archaeoentomological methods was seen as the only way to apprehend the complexity of human history and the human–environment interactions in the area.

2 Found in the frame of the La Lède du Gurg excavation in July 2015, wattle structure ST7 was transferred to the ARC-Nucléart laboratory in Grenoble for restoration and consolidation.

The initial setting up of such an interdisciplinary, multi-proxy program was made possible thanks to the LitAq project, funded by an original joint research initiative grouping two different Clusters of Excellence (LabEx) at Bordeaux University: LaScArBx (Bordeaux Archaeological Sciences) and COTE (COntinental To coastal Ecosystems: evolution, adaptability and governance). Several disciplines in coordination have thus contributed to the archaeological and palaeoenvironmental analysis.

Geomorphology and sedimentology were at the core of the project. The erosional and local constraints induced an original geomorphological method rarely deployed. The interdisciplinary and continuous monitoring of vestigial sediments was carried on from 2014 to 2020 providing a rich sediment database and making it possible to develop a specific monitoring protocol suitable for this context of severe coastal erosion. For the first time, continuous sequences were recovered from the studied sites by vertical sedimentological sampling (up to 3 m long, see Faye et al. 2019), dated (radiocarbon on wood samples and calcareous mollusk shells) and analyzed at an infra-centimeter resolution to build a reference record of past environmental changes. Those sequences provided a 10 kyr long window of new knowledge highlighting a strong link between the North Atlantic climatological contexts and the evolution of the local Médoc landscape.

Considering the nature of the remains, as mentioned above, dendrology has played an important role in the program too. Unfortunately, the region lacks a tree-ring reference sequence that would allow precise dating of the archaeological contexts identified. In order to contribute to the future creation of such a reference database,

samples from archaeological woods recovered as part of the program are systematically kept and stored under controlled conditions. Oak wood from the Mesolithic to Bronze Age levels of La Lède du Gulp and from structure AML-N-004 at L'Amélie beach was also collected for palaeobiogenetic research, contributing to a wider project on the DNA sequencing of oak species across Europe during the Holocene (Wagner et al. 2018).

Owing to the preservation of bone and other types of organic material, the core of the archaeozoological and malacology studies has focused so far on the analysis of mammals found in the Neolithic levels of La Lède du Gulp (Verdin et al. 2018) and the study of oysters and other mollusk levels found in L'Amélie beach. The presence of insects in the archaeological levels of La Lède du Gulp seems to have escaped the notice of researchers working on the site in the 1980s and 1990s, as there is no published study of this type of remains. Our recent research in the area has confirmed the presence of a significant number of very well preserved beetle remains (Coleoptera) and evidence of the presence of several other insect orders within the archaeological levels at La Lède du Gulp and L'Amélie beach, providing unpublished and relevant information on the uses of landscape by the human communities that complement and enrich the information obtained from the study of wood and sediments. A dedicated archaeo-entomological study of insects was begun in 2018, and the results so far obtained are encouraging (see below, Results). Added to this, 50 samples of sediments were analyzed for palaeoparasitology by optical microscopy after a bench treatment using the RHM (rehydration–homogenization–micro-sieving) method (Dufour and Le Bailly 2013; Dufour 2015).

Geographical Information Technologies, including near-object digital

photogrammetry, drone photography and photogrammetry, geographical information systems and terrestrial laser scanning (TLS), have been used at different stages of the research program. They contribute to the collection and interpretation of data both at the level of each discipline and in the management of the program data set as a whole.

Information is centralized in an online platform managed by the Digital Humanities unit AusoHNum (Ausonius UMR5607) in Bordeaux that is accessible to all members of the program; this platform includes a webGIS, a wiki and an intranet for the analysis and exchange of information (<http://litaq.huma-num.fr/>).

Results

The multi-proxy approach has allowed us to obtain a series of results that challenges the traditional view of the settlement and landscape dynamics around the Gironde estuary from prehistoric times to antiquity. These results can be acknowledged at three main levels: the geomorphological and sedimentary history of the coastline south of the Gironde estuary mouth; the occupation history of this region from prehistory to antiquity; and the history of the human–environment interaction.

The geomorphological and sedimentary history of the coastline adjacent to the Gironde estuary

The two main sectors considered in this paper, the northern beach of L'Amélie and the sedimentary depression of La Lède du Gulp, have been studied in detail from a geomorphological and a sedimentary perspective.

The site of La Lède du Gulp offers a detailed series of muddy to peaty deposits that cover nearly the last 10 kyr (Figure 4). These deposits were accumulated in a circular depression, probably of karstic or thermokarstic origin, and which was formed at the

last glacial/interglacial transition, potentially before or during the Younger Dryas event as deduced from the oldest ages obtained on the deepest recovered sediments, i.e., 10.5 ka cal BP (obtained on wood, SacA-50443). Analyses from one of the sedimentary columns (G3 as presented in Figure 4, after Faye et al. 2019) reveal a sharp transition between 7 and 6 ka marked by a decline in the forest cover followed by a sudden increase in the sandy deposits, which probably reflects growing eolian influence. This transition also corresponds to a major change in the sea-level rise in the northern hemisphere which thus nearly stopped, ending the Holocene thermal optimum (as also seen in the SST anomalies record in the proximal Bay of Biscay), and also corresponding to the last large event of drifting ice in the North Atlantic (after Bond et al. 2001). It is noteworthy that all of those drifting ice-events are reflected (albeit discretely) in the pollen record by a brief absence of arboreal pollen.

The complete chronostratigraphic sequence of L'Amélie beach/dune deposits was constructed from geomorphological and sedimentary surveys carried out from 2014 to 2019 (A, Figure 5). In agreement with the palaeogeographical maps produced by Pontee et al. (1998), this palaeoenvironmental framework provides a more detailed view of Holocene coastal changes of the North Médoc peninsula. Most of the intertidal sedimentary outcrops correspond to Holocene estuarine mud-flat and salt marsh deposits accumulated within a large topographic depression flanked by Pleistocene deposits (LF 1, Figure 5) dated from MIS 9 to MIS 2 (Bosq et al., 2019). The first stage of the Holocene estuarine sediment infilling is represented by a deposit of very well sorted medium-to-coarse sand (LF 2a, Figure 5) attributed to a large tidal channel, also known as the 'Soulac channel' (Allen et al., 1974; Pontee et al., 1998). The material is locally overlain by a silty sand layer containing rootlets (LF 2b, Figure 5) dated to

between ca. 7290 and ca. 7080 cal.BP (D1 and D2, Table 1) and interpreted as the gradual closure of the tidal channel from ca. 7000 cal.BP to ca. 5000 cal.BP in a context of decreasing rates of Relative Sea Level rise (García-Artola et al., 2018; Stéphan et al., 2019).

Between ca. 5660 cal.BP and ca. 4450 cal.BP (D3 to D6, Table 1), the environment changed into an estuarine intertidal mudflat as attested by a sandy mud deposit (LF 3a1, Figure) containing assemblages of foraminifera dominated by *Haynesina germanica* and *Trochammina inflata*, and brackish water species of ostracods such as *Cyprideis torosa* and *Loxoconcha elliptica*. The coastal marsh was drained by a main tidal channel that was progressively filled by the marsh (LF 3a1 and LF 3a2, Figure 5). The south-east north-west orientation of the tidal channel suggests a connection with the mouth of the estuary to the east. A dark organic-rich clayey-silt to silty-sand deposit (LF 3b, Figure 5) containing high salt marsh species of foraminifera (*Trochammina inflata* and *Jadammina macrescens*) indicates the area was bordered by halophytic vegetation. This swampy environment was sheltered by a coastal dune barrier to the west. Around 6000 cal.BP, the shoreline presumably lay a few hundred meters further west than at the present-day (Féniès et al., 2010). A well-developed dune palaeosol dated to 6170–5610 cal.BP (Dubreuilh, 1971) attests to the presence of a coastal dune complex along the Médoc coastline during this period. As further evidence, a humate-impregnated black sandstone cropping out on the northern part of L'Amélie beach (LF 3c, Figure 5) corresponds to a podzolic fossil soil profile commonly developed in coastal dune deposits (Pye and Tsoar, 2009) at the interface between sand dune swamps and stagnant lakes (Lapen and Wang, 1999).

This first stage of estuarine deposition was interrupted by a major episode of marine erosion dated from ca. 2750 to ca. 2570 cal. BP (D7 to D9, Table 1). In the central part of L'Amélie beach, a clear erosional surface is characterized by a pavement of *Scrobicularia* shells and the deposition of reworked blackened sandstone pebbles, clay and various sizes of gravels and pebbles (LF 3d1, Figure 5) produced by wave erosion of underlying units. At the end of the erosional phase, the tidal channel was filled by inclined *Scrobicularia* and organic interlayers (LF 3d2, Figure 5). Geological surveys conducted in the mouth of the Gironde also suggest an abrupt change in the hydrodynamic conditions of the estuary due to large breaches of the coastal dune barrier responsible for the formation of a large shelly ridge dated to ca. 3000–2500 cal.BP (Pontee et al., 1998; Clavé, 2001).

Between ca. 2240 and ca. 1200 cal. BP (D10 to D15, Table 1), the second stage of estuarine deposition is represented by Litho-facies 4 and 5a (Figure 5), formed respectively by a clayey-silt deposit with foraminifer assemblages dominated by intertidal mudflat species and by an organic-rich clayey-silt deposit with foraminiferal content indicating a salt marsh environment (*Jadammina macrescens*, with a few occurrences of *Haynesina germanica* and *Gavelinopsis praeegeri*). Several tidal channels filled by organic-rich clayey-silt sediment frequently layered with a high density of oyster shells mixed with mussels and *Scrobicularia* shells were observed in the field (LF 5b, Figure 5). Marsh deposits were sealed by a thin peaty silty layer with abundant phragmite debris dated between ca. 1280 and 1200 cal.BP (D16 to D18, Table 1). This high saltmarsh deposit contains a large sand fraction consistent with invasion of the marsh by sand dunes as is highlighted by the dune sequence (LF 5c, Figure 5).

From ca.1990 to ca. 960 cal.BP (D19 to D27, Table 1), the estuarine salt marshes were gradually buried beneath eolian sands associated with the northward progradation of a coastal dune barrier. The dune sequence is subdivided into five aeolian sands units (LF 6 to 10, Figure 5) from the base to the top, separated by three layers of palaeosols or organic-rich sediment. Two main periods of dune stability are recognized: (i) from ca. 1990 to ca. 1640 cal.BP (palaeosol 0, Figure 5), (ii) from 1260 to 960 cal.BP (palaeosol 1, Figure). These periods were interrupted by phases of massive eolian sand invasion dated from 1640 to 1250 cal.BP (Units 7 and 8, Figure 5) and after ca. 960 cal.BP (Units 9 and 10, Figure 5). A shorter third period of stability is also represented by a thin humic layer between stratigraphic units 9 and 10. Based on sedimentological evidence, unit 9 is associated with a strengthening of the wind regime dated to the cool ‘Little Ice Age’ (LIA; ca. 450–150 cal.BP), while unit 10 formed over recent centuries before the dunes were artificially stabilized by pine forest.

The occupation history from prehistory to antiquity

The two main areas where human activities have been recorded, La Lède du Gulp and L’Amélie, reflect similar settlement dynamics. However, while human occupation at La Lède du Gulp is spatially constrained in a sedimentary depression, archaeological remains at L’Amélie are found in scattered locations and in different sedimentary levels (Verdin et al. 2018; 2019). Evidence for Mesolithic and Early Neolithic occupation is so far limited to La Lède du Gulp, where the excavations by J. Roussot-Larroque identified evidence of human activity in the lower layers of the sedimentary sequence (Roussot-Larroque, 1995, 76-80). Conversely, the Middle and Late Neolithic are well represented

in both areas, the most characteristic structures from this period being wooden pits with wattle, stake or plank linings (Figure 3). While the role of some of these pits as wells cannot be dismissed, most of them seem to have been used at some stage in the salt production process. The environmental conditions for this period show the retreat of the forest cover, a situation that seems coherent with the increased occupation of the sector as evidenced from the presence of animal tracks, forest clearance and the spread of pastures (e.g. Roussot-Larroque, 2007).

The end of the Neolithic (III millennium BC) is scarcely represented in the occupation sequence. At La Lède du Gurg, the transition to the early Bronze Age was identified in the 1980 and 1990s as a thin layer trampled by small ruminants (Roussot-Larroque and Villes 1988, 45), while recent research has shown that this level corresponds to a break in the sedimentary record (Verdin et al. 2019; see also Figure 4). At L'Amélie a pit lined by stakes (AML-N-004; VERA-51336, 3984 \pm 70BP, 2854–2812 [3.3%] or 2746–2726 [0.9%] or 2697–2287 [91.2%] cal. BC 2 σ)³ and the recently excavated wooden structure ST35 (AML-N-010-ST35; Beta-541487, 3800 \pm 30BP, 2339–2139 cal BC 2 σ) are currently the only evidence for this period.

The Early and the Middle Bronze Age were major phases of occupation. Evidence for metal production and metal hoarding has been found at both locations. At L'Amélie, ceramic vases containing axe deposits of the so-called Médoc type have been reported since the 1980s and 1990s; in 1993, natural erosion and the construction of breakwaters unearthed one such hoard containing 72 axes for a total weight of 53 kg of metal (Coffyn et al. 1995).

3 All radiocarbon dates in this paper have been calibrated using the IntCal13 calibration curve in OxCal (<https://c14.arch.ox.ac.uk/oxcal.html>)

The Early Iron Age marks the third important phase of activity on the sites of La Lède du Gulp and L'Amélie. The production of ignigenous salt is attested by pottery (briquetage) debris at La Lède du Gulp, and substantial levels of the same type of material at L'Amélie attest to the presence of large-scale production (Verdin, 2015). Several pits lined with planking, wattle and stakes suggest a function related to salt production, using techniques similar to those implemented in the Neolithic and in the same type of intertidal estuary marshland.

Roman antiquity left many traces of intensive settlement of the marshland. The only site that could be interpreted as a permanent habitat is La pointe de la Négade, excavated in the 1970s–1980s by J. Moreau (Sion 1994, 301-303) and located about 1 km north of La Lède du Gulp. At L'Amélie, antique ceramic material, coin hoards and a brass wild-boar standard from the end of the first century BC were also found in those decades (Verdin 2015). It seem that salt production, so relevant during the Neolithic and the Early Iron Age, did not continue beyond the beginning of the first century AD.

The history of the human-environment interaction

As we have seen, most of the Mesolithic and Early Neolithic evidence came from the early excavations at La Lède du Gulp. The oldest levels are located in the center of the depression, about 2.50 m below the present-day level of the beach. They are made up of compact peaty clay containing large ligneous remains (whole trunks) that collapsed into the peatbog, together with branches, twigs, leaves and seeds. The recent excavations showed very little evidence of anthropic activity, but the radiocarbon

dates obtained agree generally with the dates formerly published by J. Roussot-Larroque for equivalent levels (Verdin et al. 2019).

More information can be inferred for more recent periods. The excavation of two adjacent wooden structures (AML-N-ST8 and AML-N-ST19) at L'Amélie in September 2017 confirmed the intense exploitation of the coastal strip of the estuary by the human societies of the Middle and Late Neolithic. ST8, a wood and stone-lined rectangular pit was radiocarbon dated to 3793–3659 cal. BC 2σ (SacA-51451, 4960 \pm 30 BP); ST19, a circular shallow pit, was radiocarbon dated to 2460–2273 [79.9%] or 2257–2208 [15.5%] cal. BC 2σ (SacA-51450, 3855 \pm 30 BP). What is more, the discovery of two coprophagous beetles associated with the wooden structure of ST8 confirmed the presence of comparable organic remains to those at La Lede du Gurp. The exceptional preservation conditions of the two specimens allowed their identification at the species level, and it could be established that both specimens correspond to *Geotrupes spiniger* -Marsham, 1802- (Scarabaeoidea: Geotrupidae) (Figure 6, A). One of these specimens has been radiocarbon dated (quitine) to the Late Neolithic (Beta-521042, 4510 \pm 30 BP: 3352–3262 [32.7%] or 3251–3099 [62.7%] cal. BC 2σ). Anatomical remains from a third insect have also recently been identified embedded in LDG-ST7, a wattle structure dating from the Late Neolithic. The date of 3331–2931 cal. BC 2σ (Beta-423524, 4440 \pm 30 BP) obtained for this structure places it in the same chronocultural framework as the insect from AML-N-ST8. An exploratory study carried out in 2019 highlighted the effect of anthropization on the coastal environment through a comparative archaeoentomological study of Structure 35 (Late Neolithic) and Structure 2 (Antiquity) of L'Amélie. From the great number of insect remains attributed to woodland and hygrophilous species, our first results confirm the

existence of a humid forest environment that was open only locally during the Neolithic period. The observed succession of insects indicates a progressive opening of the environment until antiquity. Finally, the abundance of coprophagous and saprophagous scavenger beetles and of fly puparia registered in Structure 2 strongly suggests that this structure functioned as a manure pit at the end of antiquity; similar structures have recently been reported elsewhere for the Bronze Age on the basis of archaeoentomological analyses (Buckland and Buckland 2019), confirming the potential and opportuneness of these studies in support of archaeological and palaeoenvironmental interpretation. The archaeoentomological survey, far from being complete, will make it possible to provide relevant information on both the evolution of local biodiversity and the interactions between past societies and the coastal environment.

At La Lède du Gulp, during the excavation campaign of 2014, soil samples were collected from different areas using a protocol which included the full identification of the sedimentary matrix (Verdin et al. 2018). Palaeoparasitological analysis on these samples revealed several taxa of parasites, including a family Capillariidae and two genera of helminths, *Paramphistomum sp.* and *Trichuris sp.* A majority of the samples analysed, 80% (40/50), contained at least one of these taxa. Capillariidae are present from the Mesolithic to ca. 7938–7896 [5.1%] or 7875–7604 [90.3%] cal. BC 2 σ (Gif-48068-PR5, 8725 \pm 40 BP, LDG layer US1039-B002). This is the oldest occurrence of this taxon identified on the European continent. Eggs identified as Mesolithic ranged in size from 61.9 \pm 1.7 μ m in length to 29.7 \pm 1.6 μ m in width and had either smooth or punctuated shell ornamentation (Figure 6, B). The ornamentation and sizes of the eggs suggest that they might be related to cold-blooded vertebrate species such as amphibians

or fish: *C. tritoniscristati*, *C. tritonispunctati*, *P. brevispicula*, *P. salvelini*, *P.*

tuberculata, *S. petruschewskii*. In the Neolithic levels of La Lède du Gurg,

Paramphistomum sp. and *Trichuris sp.* eggs were found in addition to Capillariidae.

Eggs of *Paramphistomum sp.* were found in 20% (10/50) of the samples. The eggs were

$143.6 \pm 4.4 \mu\text{m}$ long and $87.6 \pm 3.3 \mu\text{m}$ wide. *Paramphistomum sp.* is a parasite of wild

or domestic ruminants (cattle, goats, deer, sheep) (Figure 6, C). *Trichuris sp.* eggs were

found in 46% (23/50) of the samples. The identified eggs were $52 \pm 1.7 \mu\text{m}$ long and 27

$\pm 1.7 \mu\text{m}$ wide (Figure 6, D). The projection of egg size (Figure 6, E) shows that the

eggs can be related to two *T. suis* species (pig and wild boar) and to humans (*T.*

trichiura) with a propensity for the latter. It can therefore be retained as one of the

major results of this analysis that the species *T. trichiura* found in this deposit was

associated with humans; most often its presence is linked to poor hygienic conditions,

being representative of fecal-borne diseases.

Discussion

The multi-proxy approach to the human settlement and landscape dynamics along the coastline beside the Gironde estuary has proven to be essential for our understanding of the interaction between human societies and the natural landscape from a long-term chronological perspective. This approach appeared to us as the only way to solve the paradox between the opportunity represented by the scientific study of sediments exposed as a result of the effects of current climate change and human pressure on coastal areas and their destruction by these same agents.

The originality of this program lies in the joint analysis of human and

sedimentary remains from a wide range of disciplines, epitomized by the joint desk-planning of interventions, the joint organization of field campaigns and the joint discussion of scientific results. Owing to the exceptional nature of some organic remains in the region, the program has also implemented and integrated innovative approaches to human–environment interaction from young disciplines such as palaeoparasitology and archaeoentomology; the identification of taxa, the interpretation of palaeopathological and palaeoenvironmental information and the dating of some of these remains (i.e. insect quitine) are all relevant results that significantly supplement our interpretation of the whole settlement and landscape dynamics in the area. While our current knowledge of the sedimentary and landscape evolution of this region has been published in greater detail elsewhere (see Verdin and Eynaud 2019), it is worth emphasizing that the intense occupation of this area during certain periods of human history is related to the development of marshy environments. As already noted for the archaeology of other regions of Western France (e.g. Langouët and Daire 2009; Gouletquer and Weller 2010; Ard and Weller 2012; Billard and Bernard 2016) and Western Europe (e.g. O’Sullivan 2001; Bell and Neumann 2007; López-Romero et al. 2015; Robertson and Ames 2015), the exploitation of the marshy and/or estuarine milieu was a priority for societies living in or near the coastal strip. What is striking from the evidence collected in North Médoc is that a significant part of this exploitation is presented to us from exceptionally preserved and typologically rare organic material remains.

Thanks to the financial and institutional support of several research units and administrations and, critically, to the commitment of professional and amateur

contributors, scientific research is still today being performed in the area. Stemming from the interdisciplinary experience we have detailed in this paper, evidence of human activities, landscape and geographical changes is continuously being recovered and interpreted. We are, however, aware that a significant – most probably major – part of the human and environmental history of this region has already been destroyed by relative sea-level rise and coastal erosion. This is why this multi-proxy research has to be intensified before the remaining scientific information preserved in the intertidal area and beneath the dune horizon is lost.

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Table 1. Samples and radiocarbon dates for the morphological and sedimentological chronostratigraphical sequence at Amélie beach. P. Stéphan.

Figure 1. Location of the study region with indication of the Amélie beach (AML) and La Lède du Gulp (LDG) in the general context of SW France. Basemap EU-Digital Elevation Model (EU-DEM). CAD E. López-Romero.

Figure 2. La Lède du Gulp, first survey and sampling campaign in March 2014 (photo N. Prévôt).

Figure 3. Neolithic wooden pits and wattle structures. A: Structure AML-N-001-ST8 at Amélie beach. B: Wattle structure LDG-ST8 from La Lède du Gulp. Photos F. Verdin, 2017.

Figure 4. A: Sedimentological and palynological data obtained on La Lède du Gulp archeological site (G3 northern sampling, after Faye et al. 2019) compared to B: SST anomalies reconstructed in the proximal southern Bay of Biscay (Capbreton margin) after transfer functions applied to foraminifera assemblages (Eynaud et al. 2018) and to C: the drifted-ice in the North Atlantic after Bond et al. (2001) over the last 10 ka BP. Global temperature anomalies (D) from the compilation of Marcott et al. (2013), and the long term global mean sea-level change (E) (zoomed after Clark et al. 2016) have been added to figure global Holocene changes. Grey bands identify events of high ice-rafting in the North Atlantic supposed to mark cold phases of the polar front southern migration. The green band underlines dense forest cover as seen within the G3 record. Analysis and CAD F. Eynaud.

Figure 5. Along the Amélie beach, (A) distribution of coastal sediment outcrops based on topographic, morphological and sedimentological field campaigns realized from 2014 to 2019, (B) reconstructed litho-stratigraphical section of coastal deposits and (C) chronostratigraphical sequence supported by radiocarbon dates (numbers refers to Table 1). CAD P. Stéphan.

Figure 6. A: (Left) L'Amelie, AML-N-002-ST8; perfectly well preserved subfossil beetle specimen "in situ" (*Geotrupes spiniger* (Marsham); photo E. López-Romero) C14 dated to c. 3352-3099 cal. BC 2σ (Beta-521042, 4510 \pm 30 BP). (Right) Same species, present-day specimen, in dorsal and ventral view (identification and photo J.B. Huchet). B-C: Parasite eggs from the sediments of La Lède du Gulp (identification and photos A. Hoffmann); *Capillariidae* (type *petruschewskii*) 60,3 x 28,5 μm . (B), *Paramphistomum*. sp. 142 x 85,3 μm . (C), *Trichuris trichiura*. 52,3 x 25,4 μm . (D). E: Projection of *Trichuris* sp egg sizes; range of sizes of *T. suis* (yellow), *T. trichiura* (red) based on B. Dufour's synthesis (2015: 185-186). Analysis A. Hoffmann.